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Foreword

Dear EDSI 2016 Conference Participants,

We are honored to welcome you in Helsinki for the 7th Annual Conference of the European Decision Sciences Institute. The Conference is organized and hosted by the Department of Information and Service Economy of Aalto University School of Business together with the subject of Supply Chain Management and Social Responsibility at the Hanken School of Economics and the National Defence University.

This year the Conference Theme is “The Water Footprint in Decision Sciences”. It aims to draw special attention to how decision sciences might contribute to the development of means to assure the access to clean water in a sustainable way, for individuals and for industry, globally.

Clean water has become a scarce resource on the planet. Sweet and salty water is needed everywhere. In many places, drinking water is running out, oceans polluted so that they are no longer able to produce enough food for the growing human population. One in ten persons lack access to safe water. Every 90 seconds a child dies from a water-related disease. One of the major United Nations Sustainable Development Goals is therefore a goal to “ensure access to water and sanitation for all”. Every $1 invested in water and sanitation provides a $4 economic return. The water crisis is the No. 1 global risk based on impact to society (as a measure of devastation), as announced by the World Economic Forum in January 2015. Also, the industry suffers from a lack of clean water.

This Boat Seminar on the Baltic Sea creates a unique setting to focus on the "Water Footprint".

As the Conference fosters interdisciplinary research, we have invited contributions from all disciplines relevant to decision making and decision processes, in addition to the Conference Theme.

The Conference attracted research based on several methodological approaches: conceptual, simulations, modelling, surveys, case based research, and papers based on involvement of humans as research participants.

We thank all the researchers and authors who are contributing to the success of the Conference.

I wish to express our gratitude to the Scientific Committee and to the reviewers for their invaluable contribution to the Conference. Special words of appreciation are due to professors G. Keong Leong and Krishna S. Dhir, for organizing a Doctoral Consortium.

On behalf of EDSI 2016 Organizing Committee, most warmly welcome to the 7th Annual EDSI Conference in Helsinki, Finland.

Juha Honkonen, Györgyi Kovács and Markku Kuula
Conference Chairs EDSI 2016

Keynote Speakers

- **Sirpa Pietikäinen**
  Member of the European Parliament
  "How decision makers evaluate complex environmental issues in the EU"
- Professor **Karen Spens**
  Rector, Hanken School of Economics, Finland
  "The new way of doing good at universities"

- **Pamela C. Nolz**
  Scientist, Mobility Department, Dynamic Transportation Systems, AIT Austrian Institute of Technology GmbH, Austria
  "Water distribution in disaster relief"

Introduction

This book contains the Proceedings from the Seventh Annual European Decision Sciences Institute EDSI Conference, hosted by the Aalto University.

The Book includes research papers, for which a full manuscript has been submitted.

A selection of the Conference papers will be invited to be submitted to Operations Management Research: http://link.springer.com/journal/12063.

The unique Theme for this year's Conference is "The Water Footprint of Decision Sciences".

The list of this year's topics include:

- Behavioral Aspects of Operations Management & Supply Chain Management
- Sustainability/CSR/Social Enterprise Panel
- Supply Chain Operations Management
- Supply Chain Risk Management
- Sustainable Supply Chain Management & CSR
- Innovations in Information Technology Applications/Innovative Education
- Innovative Applications in Modelling and Decision Techniques
- Globalization of Manufacturing
- Humanitarian Logistics
- Public Sector Decision Making/Public Procurement
- Advancing Theory on Support Chains

MOVING MANUFACTURING OFFSHORE AND BACK HOME: A CASE STUDY ANALYSIS (FP)

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Abstract

The motivations underlying manufacturing reshoring decisions has been studied separately from the offshoring phenomenon – which foregoes the relocation at home – and its drivers. This seems to implicitly deny the conceptualization of reshoring as a possible further step in the internationalization strategy of firms and possibly undermines a deep comprehension of this phenomenon. Through a multiple case study approach, our paper seeks to fill this gap by analysing and classifying the principal drivers that led to offshoring and then to reshoring manufacturing activities. We focus on four Italian companies competing in traditional sectors (mountain shoes, suitcases and zippers) for which the "Made in" is likely to represent a strategic element. We apply the theory-based interpretative framework proposed by Fratocchi et al. (2016), which distinguishes the reshoring drivers on the base of company's goals and their "locus" in terms of internal/external environment. We summarize the main results into nine observations that encompass three key aspects of offshoring and reshoring decisions: Why (the "nature" of offshoring/reshoring drivers); How (governance modes); and Where (geographical locations).

Keywords: Manufacturing Reshoring, Offshoring, Made-in effect

Introduction

Since the early 1990s offshoring has emerged as one of the most widespread strategies adopted by Western companies in order to maintain or to foster their competitive advantage (Contractor et al., 2010). Although the offshoring phenomenon is far from petering out, in the last decade a counter trend has emerged whereby companies that had offshored their production to either the Far East or Eastern Europe have started bringing production operations back to their home countries or are adopting a regional location strategy (Kinkel, 2012; Ellram et al., 2014).

This phenomenon, known to most with the label "reshoring", was first discovered by the popular press, which built a case out of the fact that some prominent large manufacturers were bringing jobs back to the home country. While at first reshoring seemed to be confined to large companies, which more easily attracted the attention of the press, there is solid evidence that it also affects SMEs (Fratocchi et al., 2016). Further, reshoring does not appear to be tied to specific instances of industry restructuring, since it spans heterogeneous sectors in terms of knowledge and technology content (Kinkel, 2012; Fratocchi et al., 2016).

In the scholarly debate on reshoring the question that has attracted the greatest attention has been "Why firms reshore?". The investigation of motivations for internalization/de-internalization patterns has been defined as always "purposeful and goal oriented" (Benito, 2015), and therefore represent key elements of firms' international deployment. Further, the analysis of motivations, in addition to responding to "Why" sort of questions, provides the basis for the understanding of which value activities are involved in internationalization, where activities are located, and how they are governed (ibid.).

A wealth of very different motivations of reshoring have been proposed in the literature (Fratocchi et al., 2016; Foerstl et al., 2016). The very first hypothesis put forward posited that reshoring arises from the correction of managerial errors such as insufficient planning and knowledge of the offshore location (Kinkel and Maloca, 2009). Later, reshoring was acknowledged as a response to a fully rational offshoring decision, and determined by changes in the offshore or home country environment, such as the rising total costs of ownership in China, or the lower costs of energy due to falling gas prices in the West (Simchi-Levi et al., 2012; Tate, 2014; Martinez Mora & Merino, 2015). Other scholars have argued that reshoring may follow from the inability of firms to solve complex challenges created by offshore production (Manning, 2014). The heterogeneity of motivations hints at the fact that “multiple” reshoring typologies may be at play (Foerstl, 2016), possibly influenced by factors such as the firm’s offshoring/internationalization path, the firm’s dimension, its strategic focus, and the industry of activity.

Other authors have provided evidence that in some sectors reshoring may be tied to consumers’ perception of a higher quality of western production (“Made in” effect”; Ancarani et al., 2015; Fratocchi et al., 2016; Martinez-Mora and Merino, 2014; Tate, 2014) or to the perception of the moral righteousness of producing at home (Grappi et al., 2015). Surprisingly enough, the investigation of the motivations underlying reshoring has mostly been undertaken separately from the analysis of the offshoring process that predated them (Gylling et al., 2015). This disconnection implicitly denies the view of reshoring as one of the steps in the internationalization strategy of firms (Fratocchi et al., 2014), and tends to depict reshoring as an “odd” phase when compared to a more “orthodox” linear model of international expansion, as predicted by theoretical approaches such as Internationalization theory (Vernon, 1967) and Internationalization Process Theory (Johanson and Vahne, 1977).

Our paper attempts to fill this gap by pursuing the following goals: (1) to understand the principal motivations that led to offshoring and then to reshoring production and (2) to explore whether offshoring and reshoring can be considered part of the same internationalization strategy (e.g., they represent stages of a fully rational internationalization and competitive strategy).

Because addressing the above research goals requires detailed historical company information, the case study methodology emerges as the optimal approach. Further, since reshoring is a contemporary phenomenon still in the making and only partially investigated, we selected the inductive case study methodology with multiple cases (Yin, 2003; Patton, 1990). We analysed four companies operating in traditional sectors of the economy (footwear, fashion, and travel gear and accessories) for which the “Made in” is likely to represent an important element of customer value. The headquarters of the four companies are all located in Italy, i.e., one of the premier countries for which the “Made in” label is a synonym of quality and excellence.

Results allows us to propose nine observations encompassing three key aspects of offshoring and reshoring decisions: Why, i.e., the “nature” of offshoring/reshoring drivers; How, i.e., the offshoring and reshoring governance modes; and Where, i.e., the geographical location of the offshored and reshored activities.

The paper is organized as follows. The first section presents a literature review concerning the main offshoring and reshoring drivers. We then explain the multiple case study methodology adopted. In order to answer our research questions we undertake a within case and a cross case analysis. Finally, we present some concluding remarks.

Literature review

Literature review approach

Two streams of studies were deemed to be of potential interest for our research: (1) offshoring motivations and (2) reshoring motivations.

To ensure objectivity, rigour, and transparency, the content-based structured literature review methodology was applied to these two streams of studies. Structured literature review has been defined as “a systematic, explicit, and reproducible design for identifying, evaluating, and interpreting the existing body of recorded documents” (Fink, 2005: 6). Content-based literature review is a type of structured literature review in which content analysis is employed as a tool for examining the studies (Seuring and Gold, 2012). In particular, we decided to follow the step-based process model for content-based literature review proposed by Seuring and Gold (2012) [1].

The ***first step*** was the "material collection". As far as offshoring is concerned, the following string was searched in Elsevier's Scopus: (1) ("offshoring" OR "off-shoring") AND ("motivation" OR "driver") referred only to title, keywords and abstract. Since this topic is multidisciplinary, i.e., addressed by several disciplines and journals, we decided to perform a keyword search without any reduction in the scope of the journals (Seuring and Gold, 2012). This allowed us to identify 280 papers on offshoring motivations. We then employed a set of inclusion/exclusion criteria: (1) peer-reviewed journal papers were included while conference papers, reports, books, book chapters were excluded; (2) papers written in English were included while papers in other languages were excluded; (3) empirical papers were included while conceptual/technical papers were excluded; (4) papers focusing on offshoring of manufacturing activities were included while papers focusing only on other activities (services, R&D) were excluded; (5) papers highlighting/discussing at least one offshoring motivation based on empirical data were included while all other papers were excluded. The final list consisted of 36 papers.

As far as reshoring is concerned, the motivations were recently reviewed and systematized by Fratocchi et al. (2016). The authors find 31 reshoring motivations in the reviewed studies and highlight 24 motivations through a secondary data analysis (16 of which overlapped with the ones found in the reviewed studies). We therefore took that work as a starting point for the material collection on this stream of studies. This literature review was updated and complemented through a keyword search on Elsevier's Scopus dataset using the terms "reshoring" and "re-shoring" only in the title, keywords and abstract based on the inclusion/exclusion criteria presented above. In particular, 13 papers were added.

The ***second step*** was the "category selection". A two-levels coding scheme was employed: (1) elementary motivations; (2) categories of drivers. With respect to the latter, the Dunning's (1998) four key goals for foreign direct investment / international production (i.e., efficiency, market, resource, and strategic assets seeking) were adopted to classify offshoring and reshoring drivers (e.g., Jensen and Pedersen, 2012; Ellram et al., 2013). However, Dunning himself (1998) acknowledges that the drivers defining a specific "raison d'être" evolve over time. With this respect, recent studies on reshoring drivers (Ellram et al., 2013; Ancarani et al., 2015) pointed out the difficulties/challenges in adopting this classification. Therefore, we decided to adopt a different framework. Analysing the extant literature we found that a classification framework of reshoring motivations has been proposed by Fratocchi et al. (2016). This framework distinguishes the relocation of manufacturing operations based on the company's goals and the predominant factors affecting the decision.

- ***Goal***. Consistent with theoretical approaches such as Resource Based View, *customer perceived value* motivations explain a relocation in terms of the firm's need to improve, protect, and maintain the critical attributes that drive customer value, such as perceived quality (Eggert and Ulaga, 2002), product innovation (Rivière, 2015; Lindič and Silva, 2011), and customer services (Stringfellow et al., 2008). Hence, relocation occurs when the current location hinders the firm's ability to develop and/or maintain distinctive capabilities (e.g., intellectual property protection; product quality; innovation potential; etc.), to access external knowledge and/or other critical resources, to understand customers' needs and provide effective services. *Cost-efficiency* motivations explain relocations as the pursuit of lower production costs, for instance stemming from lower unit of labor costs or higher labor productivity, benefits from automation, shorter logistics lead times, fewer inventories, psychic distance, lower monitoring costs, etc. Theoretical approaches such as International Trade Theory and Transaction Cost Theory can all be applied to argue that manufacturing offshoring (reshoring) stem from

[1] The second step proposed by Seuring and Gold (2012), i.e., descriptive analysis of the reviewed documents, is not presented in our paper due to space constraints.

widened (reduced) gaps in input costs between the home location and the offshore location, or the low (high) costs of coordinating distant operations and relationships.

- ***Level of analysis***. Relocations motivated by changes in the *external environment* account for changing characteristics of the business model in the industry the firm operates in, in the home and/or foreign countries, and of the global economy as a whole. In particular, the relative attractiveness of the home and host locations relies on changes in costs and/or endowment of relevant production factors, in institutional factors, in country's strategic assets, in country risk, in barriers to trade and tariffs. The *internal environment* accounts for factors such as a strategic drift of the company, the company's supply chain complexity, innovation orientation, or quest for new valuable resources.

Based on two aforementioned dimensions four categories of relocation motivations are identified,i.e., the quadrants of a 2x2 matrix. Hybrid cases (relocations driven simultaneously by internal and external factors or by the quest for customer value and cost reduction) are positioned in the side bars of the matrix.

Considering that both offshoring and reshoring are fundamentally location decision (Gray et al., 2013; Ancarani et al., 2015), we applied this theory-based framework as coding scheme for both streams of studies.

To ensure construct validity and reliability, all the four authors matched codes for all offshoring motivations and for the reshoring motivations not highlighted by Fratocchi et al. (2016) separately and solved the few differences (less than 5% of drivers) through a discursive alignment of interpretations.

The ***third and final step*** was the "material evaluation", encompassing reading the papers, analysing them and coding their contents. To avoid misinterpretations and improve process reliability (e.g., Denyer and Tranfield, 2009), each paper (except for the papers on reshoring already coded by Fratocchi et al. [2016], for which we used their coding) was independently analysed and coded by two researchers (researcher triangulation) and in a few cases of disagreement all authors were involved to reach a common conclusion/decision. The initial first level codes were revised during this stage based on coded papers, particularity for offshoring motivations.

The results of the content-based literature review are summarized in Figure 1 and Figure 2, which present the results of the coding process highlighting the drivers proposed by each paper, and briefly discussed in the following paragraphs.

Offshoring motivations

The offshoring motivation most frequently cited by the reviewed studies concerns the ***costs and productivity of unskilled labour*** in the host country (quadrant cost efficiency – external environment). Several authors (Kinkel and Maloca, 2009; Gylling et al., 2015) rank it as one of the most important motivations.

Another frequently cited offshoring motivation is the ***availability of skilled labour*** (quadrant customer perceived value – external environment). Martínez-Mora and Merino (2014) highlight that – according to all the 14 footwear companies they analyzed – some host countries offer workforce more skilled. Mohiuddin and Su (2013), for example, showed that Canadian high-tech SMEs offshored some activities to get the access to local talents pools. Mykhaylenko et al. (2015) find that this driver is important, even if less significant for manufacturing than for service offshoring.

Persaud and Floyd (2013), Arlbjorn and Luthje (2012) stated that the ***access to know how*** (e.g., innovative technologies, advanced competencies) (quadrant customer perceived value – external environment) is one of the most important reasons reported by Canadian manufacturing firms for offshoring business processes.

A further motivation cited by some authors (e.g. Arlbjorn and Luthje, 2012; Persaud and Floyd, 2013) is the ***quality improvement*** (quadrant customer perceived value – external environment). Slepniov et al. (2013) highlight that this improvement is the combined effect of some (already presented) factors available in the host country (e.g. the availability of skilled labour and the local knowledge).

A few authors (e.g., Di Gregorio et al., 2009) focus on the ***operational flexibility*** (quadrant customer perceived value – internal environment) as a relevant offshoring driver. Wang et al. (2011) found however that this it is not a significant motivation for offshoring outsourcing in China.

Mohiuddin and Su (2013) report that a further motivation for the high-tech manufacturing firms is the better ***new product development*** (quadrant customer perceived value – internal environment). This is particularly true when the knowledge of the local needs and habits is a requisite for selling abroad.

Finally, Mohiuddin and Su (2013) cite the ***economies of scale*** (quadrant cost efficiency – internal environment) as a primary motivation for offshoring. The reduction of costs allows the increase of the productive volumes bringing to further savings linked to the scale.

A cursory look at the matrix (Figure 1) reveals that – despite the offshoring motivations cover all the four quadrants – there is a higher density in the two right quadrants (i.e., cost efficiency – external and value driven – external). This may suggest a higher external orientation of offshoring choices.

While most motivations unambiguously fit into one of the four quadrants, like in the reshoring matrix a few motivations are consistent with more than one quadrant, giving rise to four hybrid areas (See Figure 1).

The ***production and logistic costs*** (cost efficiency – hybrid area) is a frequently cited offshoring motivation. Aspelund and Butsko (2010) find that it is the most important motivation for the analysed Norwegian SMEs to establish the production in low-cost countries. Aspelund and Butsko (2010) quote the developments in global transportation and telecommunication systems as factors that ensure cheap and reliable movement of goods and personnel. Temouri et al. (2010) state instead that the transportation costs continue to rise and this is certainly not an incentive to offshore the production.

Several authors (e.g., Kinkel et al., 2012; Arlbjorn and Luthje, 2012; Persaud and Floyd, 2013) agree that the ***proximity to foreign customers*** (internal environment – hybrid area) is an important offshoring driver and is increasingly gaining importance. Fontana and Prencipe (2013) report the case of a company of the automotive industry that followed the offshoring strategies of its historical customers, that moved to India and China, in order to assure physical proximity to them.

Another driver of offshoring decisions is represented by the ***government incentives*** (e.g., Fragoso-Diaz, 2015) (external environment – hybrid area). Persaud and Floyd (2013) acknowledge however that this is the less important motivation of manufacturing offshoring for the analysed companies.

Finally, a few authors (e.g., Arlbjorn and Luthje, 2012; Fontana and Prencipe, 2013) identify the ***time to market*** reduction (customer perceived value – hybrid area) and specify that this may due also to the reduction of the production lead-time.

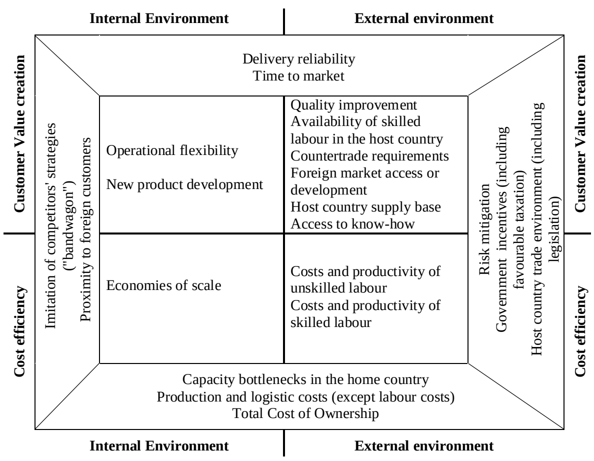

Figure 1 – Offshoring motivations highlighted in the literature

Reshoring drivers

In order to update the findings by Fratocchi et al (2016), we conducted an "incremental" literature review (see literature review approach section). In particular, we found 13 new scientific articles, which highlight 5 new variables (underlined motivations in Figure 2).

Among them, the most cited regards the ***host market reduction and/or demand volatility*** (Bailey and De Propris, 2014a; Gylling et al, 2015) which belongs to the right "hybrid area" since refers to the external environment and may have impacts on both, costs and perceived value goals. Another element regarding the host country is represented by the ***political and/or social risks*** of such external context (Uluskan et al, 2015). While we recognize that such a concept shares some communalities with the motivation "global supply chain risks" already found in the extant literature, we preferred to keep it distinct since it is linked only to the host country and not to the whole supply chain (which could encompass several countries).

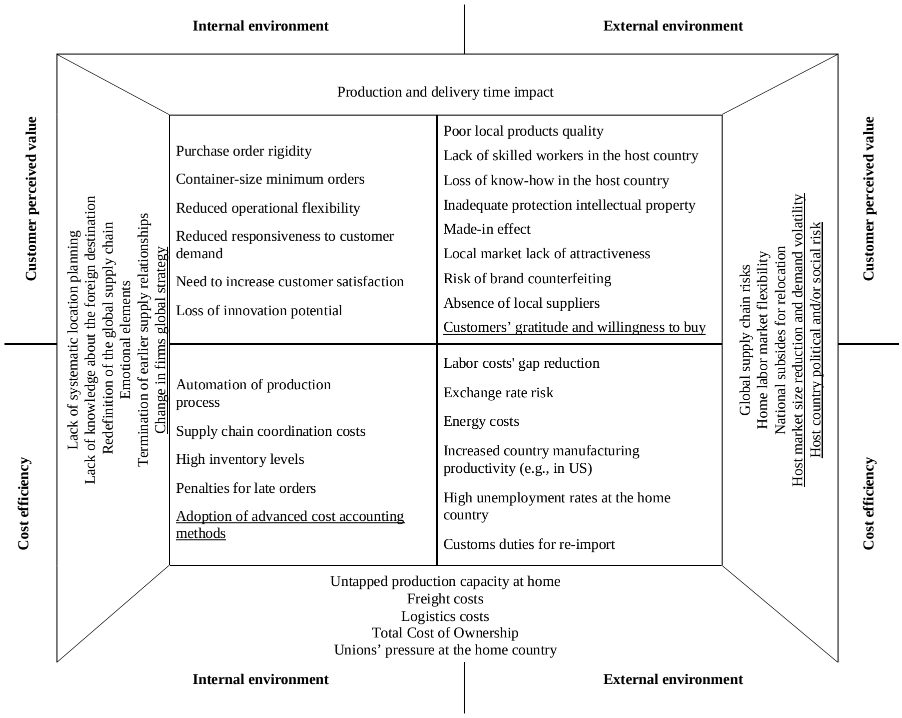

Figure 2 – Reshoring motivations highlighted in the literature
(Adapted from Fratocchi et al., 2016; new motivations are underlined)

A special mention deserves the article by Grandinetti and Tabacco (2015) which, analyzing the case of an Italian electromechanical manufacturers – point out that the ***change in firm's business strategy*** (internal environment – hybrid area) may represent a relevant reshoring driver. This is consistent with the idea that such a decision is not the mere correction of a prior misjudged decision (Gray *et al.*, 2013, Kinkel and Maloca, 2009) but a "deliberate strategy" (Mintzberg, 1985) to respond to exogenous or endogenous changes (Mugurusi and de Boer, 2014; Martínez-Mora and Merino, 2014; Fratocchi *et al.*, 2015). A similar position is shared by Gylling et al. (2015) which found this motivation analysing a Finnish bicycle maker. The same authors point out that repatriation of production activities may be driven by the ***adoption of advanced cost accounting methods*** (quadrant cost efficiency – internal environment). Such an element could – at least partially – support also the conceptualization of reshoring as a correction of a prior mistake, deriving by miscalculation of actual costs.

Finally, Grappi et al (2015) propose as reshoring motivation the ***customers' gratitude and willingness to buy reshored products*** (quadrant customer perceived value – external environment). This contribution is extremely interesting because it is the first time the reshoring phenomenon is analysed under the customer perspective. With this respect, it mirrors firm-related motivations like "need to increase customer satisfaction and reduced responsiveness to customer demand" already found in the extant literature.

Methodology

Case study method and sampling

Research on reshoring is still in its early stages and there is insufficient theoretical understanding of its motivations and dynamics (Fratocchi *et al.*, 2016). In particular, extant literature has not thrown light yet on how offshoring and reshoring strategies are related, and on whether they can be considered part of the same internationalization strategy. Our paper contributes to fill this gap.

Because of the lack of an established theory on reshoring, we employed the inductive case study methodology with multiple cases (Yin, 2003; Patton, 1990; McCutcheon, Meredith, 1993). This approach, being ‘‘particularly oriented towards exploration, discovery, and inductive logic’’ (Patton, 1990), is well suited to the development of data grounded testable theories (Eisenhardt, 1989; Voss *et al.*, 2002). In addition, it fits international business research well, because data are collected from cross-border and cross-cultural settings (Ghauri, 2004; Piekkari and Welch, 2004).

The research protocol adopted consisted of the following steps:

- *Literature analysis* to identify the key motivations involved in offshoring and reshoring initiatives (summarized in the literature review section);
- *Development of a checklist* structured into 3 sections: (1) company and interviewee characteristics (e.g., turnover, number of employees, industry, market, location of the main customers, location of production plants and other company facilities, location of the main suppliers, interviewee role and experience in the company); (2) offshoring decision (e.g., offshore location, year, product/production phase, decision makers, entry mode, dimension of the offshore unit, supply network of the offshore unit, sales market of the offshore products, organizational structure and human resources of the offshore unit, offshoring drivers); (3) reshoring initiative (e.g., year, product/production phase, decision makers, re-entry mode, supply network of the reshored unit, sales market of the reshored products, reshoring drivers). As far as offshoring and reshoring drivers are concerned, we provided interviewees with a list of drivers (see Figure 1 and Figure 2) and asked them to discuss their importance during the interview.
- *Sample selection.* The sample was composed of four companies that offshored and then (partly) reshored their production activities. This number of case firms is considered acceptable for a multiple case study analysis (Eisenhardt, 1989; Barratt et al., 2011). We included companies operating in sectors whose products are expected to be sensitive to the country of origin or “Made in” effect. This expectation is reinforced by the fact that the four companies are headquartered in Italy, i.e., a country where “Made in” is indeed an important competitive factor (e.g., in the fashion or food industries). Our case firms are also characterized by the status of small and medium enterprises (SMEs). This choice, though reducing the possibility to generalize conclusions to the overall phenomenon of reshoring, avoids possible confounding factors arising from the inclusion in the sample of large firms (e.g., easier access to finance and international networks), and therefore adds robustness to our findings. In addition, at least by conventional wisdom, SMEs may be more likely to reshore because of error corrections, since they lack the planning and market forecasting resources of large firms, and are also more likely to have offshored because of “bandwagon” effects (i.e., imitation of competitors). Therefore, the sample chosen may also allow drawing interesting conclusions on the relevance of reshoring as “error correction” (Kinkel and Maloca, 2009).The main features of the sampled firms are described in Table 1.

Table 1 – Summary of cases

Company	Sector/ product	Turnover per year (mln €)	Markets	Employees	Activities reshored	Offshore location	Years of offshore stay	Current inshore activities
Aku	Mountain and outdoor	21.5 (2014)	Italy (25%) Rest of Europe and	~330	Production of high-end segments	Romania	11 (1999 –	R&D Quality control Production (all

	shoes		North America (75%)		(~30% of turnover)		2010)	high end products and part of medium-range products)
Fitwell	High tech sport and outdoor shoes	2.5 (2013)	Italy (50%) Rest of Europe, Japan, New Zealand (50%)	18	Production of high-end segments (~40% of turnover) and high value added stages of medium segment productions	Romania	10 (1999 – 2009)	Production (all high end products and some stages of medium-range products)
Ska Italia	Zips	6 (2013)	Italy (60%) Europe (15%) China (25%)	230	Production of high-end segments (~% of turnover)	China	10 (2000 – 2010)	R&D Production (very high end products)
Roncato	Suitcases and travel accessories	48 (2011)	Italy (60%) Europe and rest of the world (40%)	~100	Production of high-end segments (~30% of turnover)	China	34 (1970 – 2012)	R&D Quality control Production (all high end products)

- *Data collection*: Structured interviews with the CEOs of the sampled companies using the checklist described above were the first source of data. The checklist was sent to each interviewee prior to the interview. Each interview was performed by three members of the research team. The information gathered through the interviews was supplemented with internal documents provided by the companies and by external secondary sources (e.g., press reports). Triangulation of multiple sources of evidence provided a stronger substantiation of results (Eisenhardt, 1989). All interviews were recorded and fully transcribed. We created a database for each case consisting of the interview transcripts, field notes, and archival data. We then developed preliminary versions of the case studies reports that were then sent to the interviewees in order to verify the accuracy of the information. As a result of the feedback received, the final versions of the case studies reports were developed.
- *Within-case analysis*. Coding and data analysis were conducted manually by three members of the research team to ensure inter-coder reliability (Duriau et al., 2007). An additional researcher was assigned the role of "resident devil's advocate" in order to discuss and resolve any disagreements. Each case was described in terms of four main macro categories (i.e., background of the company, offshoring, reshoring, present). Sub-categories were then defined for each macro-category. Offshoring and reshoring motivations were classified according to the theory grounded framework presented in the literature review section (see Figure 1 and 2).
- *Cross-case analysis*. After the within-case analysis, the cross-case analysis was performed and findings tabulated, to identify common themes and internationalization paths.

Within case analysis results

This section presents the results of the within case analysis of the four cases, focusing on the following aspects: company background, offshoring, reshoring, and present situation (i.e., following the implementation of reshoring).

Aku

Background: Aku is a medium sized company operating in the outdoor and mountain shoe sector. The company evolved from a workshop to the current arrangement, which was established in 1991. The Italian headquarters are located in the “mountain shoe” district of Montebelluna in the North-east of the country.

Offshoring: In the early nineties, due to the growing competition of East-European countries, whose **labour costs** (both skilled and unskilled) and **total costs of ownership** were more advantageous than in Western Europe, Aku began approaching Eastern Europe with several short term (outsourcing and insourcing) offshore arrangements. R&D, quality controls and sourcing of raw material remained located in Italy. At first, Aku experimented by opening own workshops with the aim to develop a local production culture compatible with the high quality standards required by its market position, and by establishing outsourcing contracts with local producers. Having gained sufficient knowledge of the local production culture, in 1999 Aku opened an own plant in Romania (Cluji Napoca), an offshoring location supported by the **availability of skilled manpower**. The transfer of operations abroad resulted also from the **imitation of competitors’ strategies**, who were too setting up shop in Eastern Europe. In fact, the leading business model of the sector called for pursuing cost cutting to face the fierce price competition. The long process of building local knowledge, of adapting to the offshore context, and of developing offshore workers and suppliers, led to quality standards offshore analogous to those at home. As Paolo Bordin, general manager of Aku puts it: “*In Romania we started from scratch. It was a long story of endurance, but now the quality of product in Romania is analogous to that in Italy*”. Hence, offshoring was mainly driven by cost reduction considerations in order to stay apace with competitors (Quadrant 2). However, given that Aku served medium to high segments of the market, the quality of human resources was a key factor in the choice of the offshore location in order to maintain the same quality of the inshore production (Quadrant 1).

At the beginning of the years 2000, Aku also started sourcing light shoes from third parties in the Far East. A small portion of turnover continued to derive from shoes designed and produced in Italy.

Reshoring: Between 2010 and 2011 Aku implemented the reshoring of high segment productions previously carried out in the Romanian plant. Production was repatriated to the historic plant in Italy. High-end sport shoes exhibit a higher technological content, offer greater possibilities of exploiting process automation, and are less dependent on the cost of manpower. According to Aku’s CEO, the need to protect the company’s knowledge and competencies, the **fear of loss of innovation potential,** and the need to guarantee **proximity of production to R&D and to marketing** were the main drivers of the decision to repatriate production. Currently the “top outdoor end” is entirely designed and produced in Italy, medium-end trekking outdoor are produced and assembled either in Italy or in Romania, while light shoes continue to be outsourced to Asia, given that these low-end segments are more sensitive to price and have a low-technology content. Other key motivations encompass the **loss of company’s know how** because of offshore production, and the need to re-establish **roots in the local industrial culture** and with the home region, given that the company is historically rooted in its territory. Hence, reshoring motivations are mainly positioned in the upper quadrants of the matrix (Quadrants 1 and 4), given that the need to enhance customer value (through innovation and improved quality of production) explain the reshoring initiative.

Present: Following reshoring (and also a partnership with Canadian Geowell that in 2009 bought 50% of Aku, easing the company out of a financial crisis and paving the way to Aku’s growth in north American markets) turnover has shown a rising trend: from 14 million euro in 2011 to 21.5 in 2014.

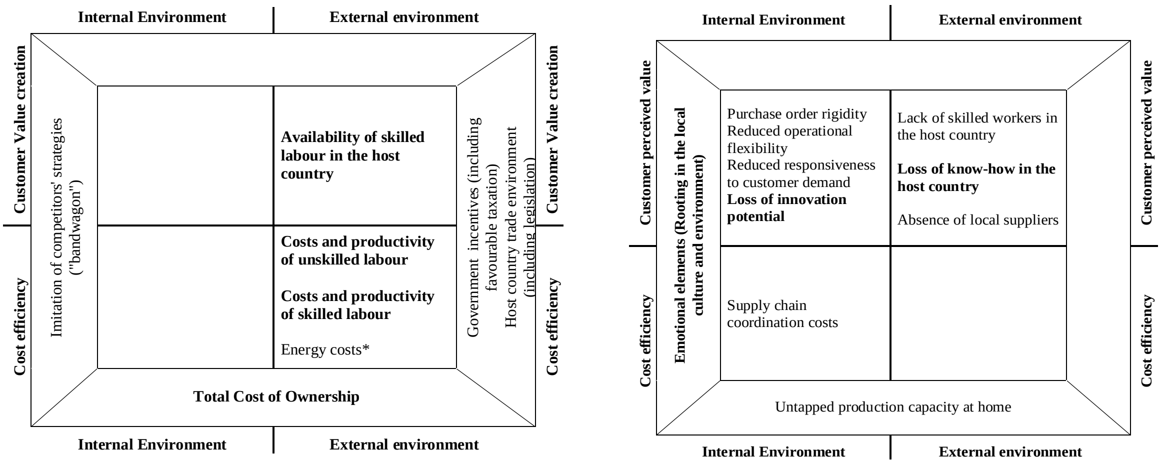

Figure 3 – Summary of offshoring and reshoring motivations - Aku (Critical motivations in bold)

Fitwell

Background: Fitwell is small company operating in the sector of outdoor and mountain shoes and whose headquarters are located in the shoes district of Montebelluna in North-East Italy. Fitwell was created in 1979 when Giuliano Grotto founded ONESport, a company specializing in the production of highly technical mountain shoes and quickly acquiring a reputation as producer of boots for Himalayan expeditions. Therefore, the company occupied a niche market characterized by high-reliability and high-quality, also thanks to the local tradition in leather processing techniques. In 1997 ONESport started a collaboration with the French group Lafuma, which bought the brand ONESport the following year. Grotto continued to work for Lafuma as a contract manufacturer, producing free climbing shoes - a collaboration that continues up to now, but also launched his own new brand Fitwell. Currently, Fitwell has opened new niche markets in areas such as canyoning and freeride.

Offshoring: In 1999 Fitwell began outsourcing its production to Eastern Europe, first in Hungary and in the Czech Republic and then in Romania, where there was a tradition for shoe manufacturing. One of the main reasons for outsourcing offshore were **pressures from the key customer** Lafuma, asking for more competitive costs that could only be achieved by producing in low cost countries (**low labour costs and lower TCO**), similarly to what was being done by most of the companies in the same sector (**imitation of competitors' strategies**). The company also benefited from greater, a looser **country legislation with respect to labour and contracts with suppliers**, and more **favourable taxation** with respect to Italy. According to Fitwell's CEO: "*I went offshore also because of the politics of globalization. With hindsight, it was a mass mistake. But if 15 years ago I hadn't done it, I wouldn't be here now. There was no other solution*". However, the high quality standards of Fitwell's shoes required a long period of supplier development and training in order to guarantee to customers standards comparable to the Italian ones*: "The cultural approach (to work) in Romania and in Italy are deeply different"*. Consistent with the goal to maintain high quality standards, the development function remained in Italy, and so suppliers of raw materials, while production was totally offshored. Therefore, similarly to Aku, Fitwell too was induced to offshore by the need to follow competitors in a race to reduce total costs, and especially costs of labour, given the high labour intensity of its productions.

Reshoring: In 2009 Fitwell partially reshored the Romanian production, deciding to manufacture in Italy all top end shoes (mountain shoes and boots accounting for 40% of turnover) and two out of the three main production stages for medium end shoes. Since all raw materials are produced in Italy, Fitwell can boast today a 100% "Made in Italy" product: "*After the global crisis, Italian companies that had offshored lost identity, therefore their strategy has changed to "top of range" products in order to acquire visibility in the market".*

Currently only the upper boot for medium range products is manufactured in Romania, given their higher sensitivity to price competition. Romanian contract manufacturers are responsible for high labour intensive production stages, while final high value added phases (e.g., assembling and gluing of the upper shoe) are carried out in Italy. Design and prototyping are outsourced to local companies. The company argues that it would be nearly impossible to reshore production stages now carried out in Romania, because over the years, local competences and know how have dwindled: "*There is a scarcity of specialized manpower and this makes a full scale reshoring impossible*".

Among the reasons for the return to Italy, the strategy to sell Fitwell as a "**Made in Italy**" brand features as prominent, as this helps the company charge a premium price. In addition, the company's need to sustain the brand's identity by improving **product quality** was a key driver of the decision. The quality differential more than offsets the higher TCO resulting from reshoring. Fitwell's CEO says: "*I am convinced that there is still market space for a small company that can make good shoes*".

Another driver was the loyalty to the home region and affective links with the local territory (**emotional elements**): "*We came back because we are rooted in the territory, because we are able to manufacture a product but to make it a quality product we must produce it in Italy*" and "*With the concept of Made in Italy we have gained as far as quality is concerned, but we have also regained the pride to produce here at home*".

The main drivers of reshoring are the direct consequence of the firm's repositioning of its product offering towards high end segments, and of its becoming a direct provider of end customers rather than being simply a subcontractor of Lafuma. This required investing in quality and branding, in addition to regaining its authenticity as a crafmanship product.

Present: Following reshoring, the company's performance has improved and turnover has risen. The company has had no second thought on the reshoring decision.

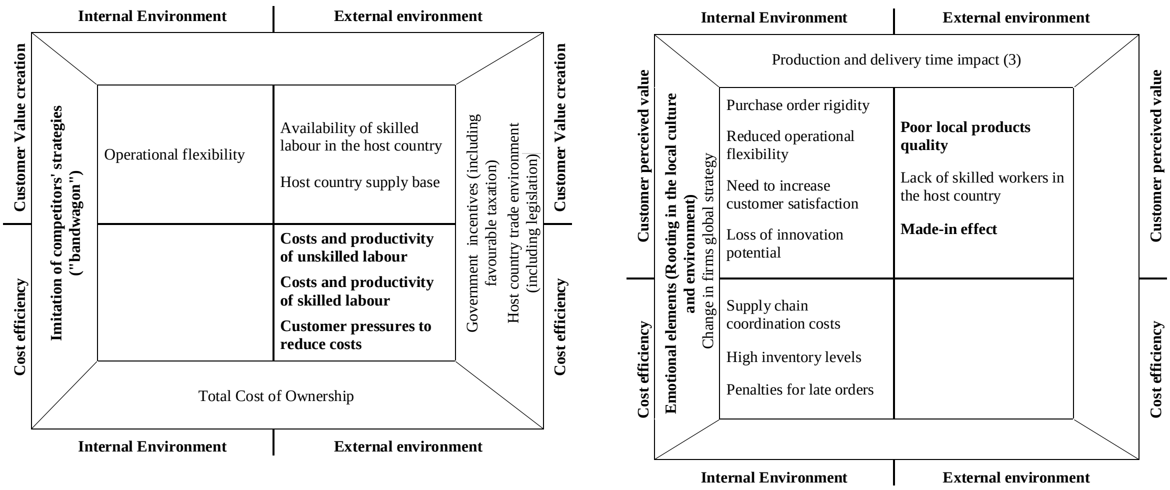

Figure 4 – Summary of offshoring and reshoring motivations – Fitwell (Critical motivations in bold)

Roncato

Background: Roncato is a medium sized company operating in the fashion sector and specializing in suitcases and travel accessories. The heydays of Roncato go back to the forties when the small craft company began production, while the industrial set up dates back to the seventies. The company boasts a record of innovation in the sector: first to use an assembly line for suitcases, first to develop a trolley, first to build light hard shell suitcases made of polypropylene.

Offshoring: Roncato's offshoring initiatives predate those of many other competitors. The company started relocating production offshore already in the early seventies, by outsourcing the production of soft shell suitcases (approximately 65% of the turnover) to suppliers in South Korea, followed by a further transfer of production to China. Competitive advantage in this segment, in fact, hinged strongly on price, and the Far East offered undoubtedly savings in terms of **labour costs** and **total costs of ownership**. In 2000, the creation of a “project and style” department in Italy allowed unifying styling between the Chinese and Italian production lines, whereas beforehand the project and concept differed in the two countries. This change provided the company with the opportunity to maintain its brand characteristics throughout the range of products offered.

Reshoring: Starting in 2009 Roncato began the reshoring of high end productions of hard shell suitcases previously taking place in China. Production was inshored to the historical plant of the company, whereas in China it was outsourced to local producers. Several reasons were at the root of the reshoring decision: the first concerns the **strategic repositioning of the brand**, which aimed to increase its share in foreign markets building on a “**Made in Italy**” image that commands a premium price. In Roncato CEO’s words “*If you want to grow abroad, well it is a different world with respect to Italy where price drives the purchase. Abroad, Italy is seen as an icon of good taste, style, quality, so for foreign buyers a product that is made in Italy not only provides a guarantee of, but also has a greater appeal.*” However, the return of top end productions to Italy was motivated not only by the quest for legitimacy in the eyes of foreign customers but also by the need to be able to improve **product quality** with respect to offshore production and boost **innovation potential**.

Present: Following reshoring, turnover has remained constant and around 40 mln euros per year, while employment has risen due to the production lines relocated in Italy.

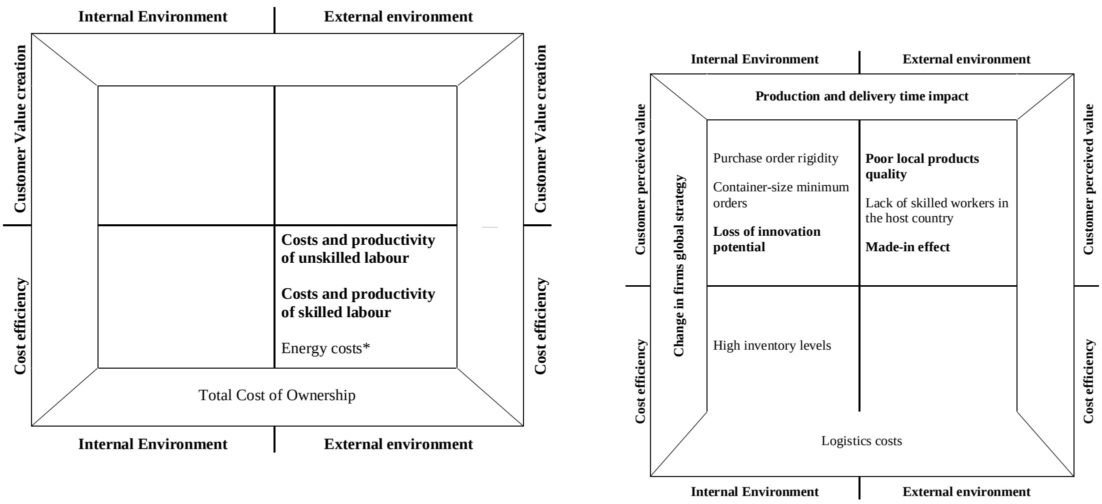

Figure 5 – Summary of offshoring and reshoring motivations - Roncato (Critical motivations in bold)

Ska Italia

Background: Ska Italia is a medium sized company operating in the fashion sector and specializing in zippers. The company was born in 1999 out of a previous company in the same sector and, since its onset, has been characterized by a global reach and high innovation. The company’s market encompasses two main segments: footwear, fashion and leather requiring a high quality, and generic apparel requiring less stringent quality standards. While competitors on the first segment are located in the West, competitors on the latter are generally located in China.

Offshoring: Ska Italia located its production facilities in China in the area of Canton, while only high value added activities such as R&D remained in Italy. The Chinese location clearly responded to the need to exploit **labour cost** advantages and a lower **total costs of ownership**, and to reap the benefits of proximity to customers (apparel and suitcase producers) (**access and development of foreign markets**). In order to comply with the past Chinese legislation (that prohibited the creation of WFOEs), Ska Italia entered the Chinese market through a joint venture with a local partner. The search for a suitable partner proved to be long, due to the difficulty in finding a medium sized enterprise that could guarantee attention to product quality.

In addition, the company benefited from **government incentives** for western firms locating in Chinese Special Economic Zones in the form of free granting of land and **favourable taxation**.

Reshoring: In 2010 the company decided to reshore part of production to Italy by opening up a new plant in the north west (through a joint venture) devoted to the production of high quality zippers for the leather fashion market. New lines were also opened to accommodate the demand from the very top segment of production coming from the fashion and the leather products markets. The rationale for relocating the high end lines back to Italy was many-fold: first, a **strategic re-positioning** of the company towards the higher segment of the market required a re-organization of production sites. In fact, it was necessary to improve **product quality** with respect to offshore production: *"There have been improvements in quality that we have been able to undertake in the Italian plant and that were difficult in the Chinese one"*. This reason aligns with brand image and the need of Ska Italia's top customers (e.g., Gucci, Ferragamo, Tods) to certify a fully "**Made in"** Italy supply chain: "*The fashion market demands a Made in Italy product, even if sometimes Made in Italy is just a cliché rather than a reality*". The Italian plant carries out only specific stages of the production process, while dying and some types of galvanic coatings are outsourced to other Italian producers. The repositioning towards higher segments also required continuous innovation. However, the **innovation potential** was at risk in the offshore location partially due to **inadequate protection of IP** in the offshore location: *"We prefer to produce our high tech range in Italy in order to protect our know-how. Taking this knowledge to China would invite the Chinese to take advantage"*.

Therefore, the key motivations for reshoring and for offshoring have been those of following customers and complying to customer needs. These included the need to improve **operational flexibility** and reduce **purchase order rigidity**, i.e., the possibility of ordering "just in time" small lots, both of which impossible to achieve through the Chinese plant.

Present: Following reshoring, turnover has remained constant and around 4 mln euro per year, while employment has risen due to the production lines relocated in Italy. The new plant is still to produce profits, due to the high initial investment.

Cross case analysis results and discussion

The cross case analysis was performed with the aim to answer three questions (Why?, How? Where?) with respect to offshoring and reshoring. This pattern of analysis has already been adopted for offshoring (Mugurusi and De Boer, 2013) and reshoring (Fratocchi et al, 2014). While the "Why" question is directly related to the analysis of motivations, the other two questions arise because "important issues in companies' internationalization differ systematically across different types of motives" (Benito, 2015). More specifically, the "How" question focuses on the governance mode adopted during the offshoring and reshoring phases. Finally, the "Where" section regards the geographical location of the offshored and reshored activities.

Based on the three questions, observations were derived nine propositions for further research.

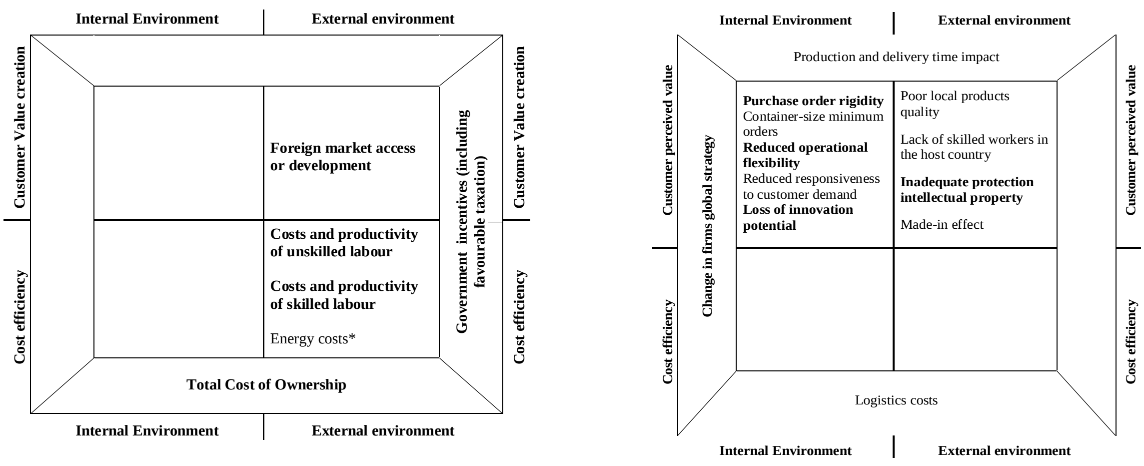

Figure 6 – Summary of offshoring and reshoring motivations – Ska Italia

(Critical motivations in bold)

Why? The "nature" of offshoring/reshoring drivers

A relevant element for the cross case analysis is represented by the nature of drivers explaining both the offshoring and reshoring decisions of the case companies. In this respect, it seems useful to refer to the four couples of matrixes reported in the within case analysis section (Figure 3, 4, 5, and 6). More specifically, we focus our attention on the four main quadrants, first highlighting changes regarding the "level of analysis" dimension and then the "goal" one. In so doing, we consider only those motivations declared as critical by the companies.

With respect to the external/internal environment dimension, all four companies decided to offshore almost exclusively on the base of "external environment" drivers (right-hand side quadrants). This finding is interesting since it suggests that external dynamics were more relevant than internal factors in explaining offshoring. This finding could be – at least partially – explained by the small/medium size of the four firms, since large and multinational companies generally implement more pro-active strategies to influence the external environment. Such a justification seems somewhat supported by the presence of location strategies either imitating competitors ("bandwagon effect") (Aku and Fitwell) or imitating customers (Ska). Turning to the reshoring decision, the "internal environment" drivers become more prominent, especially those regarding innovation potential and logistic elements. However, they appear to bear a higher weight for medium companies, while Fitwell (the only small firm in the sample) is only partially influenced by them, since none of its main motivations for reshoring belong to quadrant 4. This could be partially explained by the lower amount of in-house resources and competences that small firms can generally leverage.

With respect to the "goal" dimension, there is a marked difference between the offshoring and reshoring initiatives. The first decision (offshoring) is generally driven by "cost-efficiency" (mainly of the labour component; Quadrant 2). This findings is interesting because it suggests that even companies producing goods characterized by a significant "made in effect" – that is the higher value perceived by customers on the base of the "country of production" - may decide to change their production location on the base of costs elements. In this respect, such a strategy is somewhat fully coherent in the case of Fitwell, which – at the time of offshoring – was mainly a subcontractor (70% of total sales deriving from other companies' trademark products), and never offshored high range products (high-tech mountain boots). In a similar vein, when Roncato decided to offshore both soft-shell (low range and price sensitive) and hard-shell suitcases (medium to high range), it offshored only the production of hard-shell made of polycarbonate and not the polypropylene ones that are more hi-tech and very high range). When it came to reshoring, Roncato reshore only the hard shell and still produces the soft shell in China.

Unlike the purely cost-driven offshoring strategies of Fitwell and Roncato, Aku was motivated also by the "availability of skilled human resources in the host country" (Quadrant 1) and Ska by the "foreign market access or development" (Quadrant 1). These two drivers refer both to "customer value creation" (upper quadrants). Therefore, while Fitwell and Roncato decided to offshore to build up their competitive advantage on a "cost leadership strategy" (Porter, 1980); Aku and Ska tried to simoultaneously implement the "differentiation strategy" and the "cost leadership" one. This strategic choice is generally considered as quite risky in the medium-long period, since companies should focus on only one base (cost vs differentiation) for developing their competitive advantage (Porter, 1990). When reshoring decisions were taken, cost-related motivations were never relevant. This is particularly interesting since salaries in both offshoring countries (Romania and China) have risen considerably in the last few years. All companies' implemented reshoring decisions driven by "customer value creation" motivations (upper quadrants). In other words, reshoring decisions implemented by the case companies reflect a shift in their competitive advantage base since they totally abandoned "cost leadership strategy" to focus only on "differentiation" one (Porter, 1990). As a consequence, for the analysed companies reshoring emerges as the result of a strategic change (see, in this respect, Mugurusi and de Boer, 2014), more than the correction of an earlier managerial mistake (Kinkel and Maloca 2009). This contention is supported by the fact that all companies decided

to focus their competitive efforts on high- and medium-end products. Finally, it is worthy of notice that the “Made in effect” – that is the higher value perceived by customers on the base of the “country of production” - was a key reshoring driver for Fitwell and Roncato and partly for Ska. On this subject, a very interesting case is that of Fitwell, which reduced the weight of sales as subcontractor from 70% of total revenues (at the time of offshoring) to 20% (after the reshoring implementation), developing an own trademark for high- and medium-end products.
The above discussion leads to the formulation of the following observations:
Observation 1 – At least in labour intensive industries where the predominant motivation for offshoring is cost-reduction, reshoring follows a strategic change aiming to increase differentiation and the value perceived by the customer.
Observation 2 – Small firms are induced to offshore/reshore mainly because of external environment dynamics (the market), while for medium firms the internal environment is also significant (logistic and innovation elements).
Observation 3 – Companies whose product offering includes high-end products for which “made in effect” is relevant either do not offshore (e.g., Fitwell) or, if they offshore, they reshore in the medium term.
Observation 4 – Larger companies (Aku, Ska, Roncato) base the reshoring decision also with an eye to innovation, and the co-location of production and R&D, while smaller companies are less sensitive to innovation issues.

How? An Analysis of Governance Modes
The four companies differ in the governance mode (outsourcing vs. insourcing) adopted in the offshore location. In particular, while Roncato’s and Fitwell’s offshoring were characterised by outsourcing arrangements, Aku opened both own plants (in Romania) and concluded outsourcing contracts (in China), while Ska created a joint venture with a foreign company in China. Irrespective of the governance mode offshore, the governance following reshoring is always insourcing. Elaborating on Gray et al. (2013)’s taxonomy of offshoring/reshoring and outsourcing/insourcing yields the following summary of cases with respect to governance:

Table 2 – Offshoring-reshoring options

	Offshore outsourcing	**Offshore insourcing**
Inshore outsourcing	//	//
Inshore insourcing	Fitwell (medium end segment, Romania) Roncato (high and medium end segments, China)	Aku (high and medium end segments, Romania) Ska (high end segment, China)
Not reshored	Aku (low end segments, Romania) Fitwell (one labour intensive stage of medium end segment production process) Roncato (low end segments, China)	Aku (partially medium end segments, Romania)

In order to understand the governance mode offshore and inshore of the four case companies we take the view of Mudambi and Venzin (2010), according to whom location and governance “are strategies used to orchestrate the firm’s overall value chain” (p. 1511). Since “value creation ‘travels’ in terms of location and control, […] firms need to frequently re-evaluate and adapt their offshoring and outsourcing decisions.”(p. 1512).

Offshoring involves the assessment of which parts of the firm’s product offering and which stages of the production process are to be deployed in the offshore location. This requires the evaluation of whether core resources need to be transferred offshore from the inshore location and/or whether core resources are to be sought offshore (Hamel and Prahalad, 1990). In turn, discourse over resources is tightly connected to that of resources control, with increasing emphasis having been placed on competences and knowledge intensive production stages

(Mudambi, 2008). According to Transaction Cost Economics, the firm should hold close control over processes or stages through which the firm can generate and withhold the highest value and for which there is a risk of opportunistic behavior from third parties (Williamson, 1985).

Knowledge transfer and control preoccupations were certainly at the root of the offshoring decisions of some of the case firms. Both Aku and Ska see know-how and continuous innovation as a key source of differentiation and competitive advantage. For these reasons, high value creating activities such as R&D and marketing have always been maintained in Italy. Further, and consistent with the above, only a small portion of turnover has been outsourced to third parties.

How does governance/control link to motives? In the case of Aku, the goal of offshoring of medium and high range products was to cut costs, under the constraint that the offshore location possessed human resources allowing quality standards analogous to those at home. This entailed transferring to Eastern Europe knowledge and competences concerning medium- and high-end segments residing in Italy. The process of building local knowledge and of adapting to the offshore context went through a first attempt at subcontracting in Hungary, soon abandoned and followed by the establishment of an own plant in Romania. In fact, insourcing guaranteed better process control and easier coordination with the production phases that remained in Italy (R&D, quality control, sourcing of leather and other quality goods). On the contrary, the production of light shoes for lower end markets was outsourced to Chinese providers, given that little knowledge transfer was needed for these standardized lower end-segment products. Ska and Aku exhibit very similar patterns of offshoring with respect to quality goals and need for process control. Ska offshored to China since the early start of its activity and established a partnership with a similarly sized local company. The rationale of the partnership (rather than a subcontracting arrangement) was again to allow adjustment of equipment and production processes to Ska's quality requirements, and to ensure control over the company's know how. In addition, and unlike Aku, Ska was motivated not only by efficiency seeking but also by market seeking in China.

In short, these two firms' international expansion leveraged on in-house knowledge but at the same time was constrained by an industry business model that imposed cost cutting. Therefore, outsourcing/insourcing (control) and offshoring to low cost countries (location) can be considered simultaneous and interrelated, with no priority of the one decision over the other (Rugman and Verbeke, 2001).

This offshoring paths link logically with the reshoring decisions of Aku and Ska. The former reshored only those productions for which there was a greater need to link production to R&D (i.e., top end shoes) in order to boost the innovation requirements of this segment. For this same reason, insourcing was the governance mode chosen for reshored activities. Low-end productions remained in China, while medium-end products are interchangeably produced in Romania or Italy, given the equivalent quality standards in the two locations. For Ska, the tight control allowed by offshore insourcing led to maintain part of its production offshore and to reshore only the production of high quality zippers for the leather fashion. As in the case of Aku, the repatriation was important to boost the innovation potential of the company, given that offshoring had entailed a mere transfer of competences to the Chinese partner, and not the integration and acquisition of new knowledge offshore.

Though operating in the same sector as Aku (mountain and outdoor shoes), Fitwell's governance strategy offshore was that of outsourcing to Romanian suppliers. At the time of offshoring, Fitwell was mainly a subcontractor of a larger company (LaFuma) that pressed for lower costs. Hence, Fitwell's offshoring initiative was purely efficiency seeking. Offshore outsourcing was certainly motivated by Fitwell's small size and fewer resources with respect to Aku, which made a captive form of offshoring too onerous. The other reason for outsourcing was that Fitwell never offshored the high end segment, which leveraged on in-house knowledge relating to the production and assembly phases. Given its small size, Fitwell has never had a proper development department, and project, design, and prototyping take place through an open innovation mode. The offshore governance of Roncato's offshoring governance -like Fitwell's, was one of outsourcing, and was too cost driven: the offshoring concerned mainly soft-shell suitcases that, being price sensitive, were uneconomical to manufacture in Western countries. At the same time, Roncato did not leverage any specific knowledge on soft-shell suitcases, since this production was well developed in China with many local producers. Offshoring also included some ranges of hard-shell suitcases that can be classified as medium segment. Roncato maintained R&D and marketing activities in-house in Italy, and through time succeeded in making styling homogeneous through its Italian and Chinese production sites.

A parallel can be drawn between Fitwell and Roncato also as far as reshoring is concerned. Fitwell's decision to reshore medium end segments followed the strategic change from subcontractor of other producers to supplier of end customers with an own trademark that planned to appeal to customers based on a "Made in Italy" image. Even if Fitwell has no in house R&D reshoring has taken place through insourcing, in order to leverage on in-house production and assembly competences. Only one low value added, high labour intensive stage of the production process of medium price shoes continues to be carried out in Romania. For Roncato, while the production of soft-shell suitcases still takes place in China, the need to re-orient the brand towards "made in Italy" has led to the reshoring of medium end, high-technology hard-shell suitcases for which knowledge on materials and design reside in Italy. The insourcing decision follows from the need to establish closer ties with R&D.

The above discussion leads to the formulation of the following observations:

Observation 5 – Offshore outsourcing prevails when the offshoring is purely cost driven, whereas offshoring insourcing is preferred when there are also customer value motivations.

Observation 6 – In the industries analysed reshoring involves:

a) ***Always**: Very high-end segment products characterized by a high technology content, for which proximity of manufacturing and R&D is important (Aku, Roncato, Ska). This is true irrespective of the offshore governance mode.*
b) ***Sometimes**: Medium-end products. This is more likely to happen when the company has adopted an outsourcing mode offshore and has no strong control on production process that is critical for Made In sensitive markets (Fitwell in Romania).*
c) ***Never**: Low-end segment products with low technology content (Aku's shoes in China and Roncato's soft-shell suitcases).*

As already noted, although the governance modes offshore differ, the four companies all adopted an insourcing mode once reshored. From a strategic point of view, this reflects the need of these firms, which produce also for medium and high-end markets, to maintain a tight control on own competences. From an operational point of view, insourcing supports the effectiveness of quality controls and of inter-functional coordination between R&D and production. This leads to the following observation:

Observation 7 – Irrespective of the governance mode adopted offshore, reshoring of "Made in" sensitive products takes place through an insourcing mode.

Where? The impact on firms' supply chains

Since all the four case companies are Italians the geographical element may be investigated only with respect to the offshoring locations. As already pointed out, two companies (Aku and Fitwell) moved their productions to Romania and the other two (Ska and Roncato) to China.

First of all, it is worthy to note that the geographical destination does not exhibit any interdependence with both the timing of offshoring (since the three late comers went to China and Romania) and the governance mode (since we had insourcing and outsourcing solutions in both countries).

At the same time, is interesting to note that the companies offshored in Romania belongs both to the mountain boot industry and declared that imitation of competitor's strategy was a very relevant (Fitwell) or relevant (Aku) motivation of their decisions. After the fall of Berlin wall in 1989, formerly Eastern Europe countries emerged as both an interesting new market and a low-cost production location (especially for easier tasks like shoes assembling). In the mountain shoes industrial district of Montebelluna (to which both Aku and Fitwell belong), offshoring of manufacturing activities had been implemented since the mid-70s by large companies (e.g., Diadora and Lotto), which subcontracted their production to companies in the Far East Asia, following multinationals like Puma, Adidas and Nike). However, at the beginning of the nineties, offshoring became an imperative for Montebelluna district firms.

The impact of geographical distance on the reshoring decision seems to be confirmed by the presence of drivers regarding supply chain management elements among the very relevant and relevant motivations declared by the two companies offshored in China. More specifically, CEOs cited (although with a different relevance) technical aspects like the "purchase order rigidity" and the "container-size minimum orders". It is interesting to note that such elements were cited even by Ska which adopted an insourcing governance mode. While this strategy should have allowed to better size production lots and deliveries to the home country, the geographical distance forced the company to optimize the logistic costs with "full load" shipments.

The joint effect of the huge geographic distance and the insourcing governance mode seems to be at the base of the high relevance declared by Ska with respect to the "reduced operational flexibility" driver.

Observation 8 – Supply chain related reshoring drivers are more relevant in the case of geographically distant countries.

Observation 9 – The geographical distance and the insourcing strategic option strengthen the relevance of logistic elements as a reshoring drivers

Conclusions

Extant literature has studied the motivations underlying reshoring decisions separately from the offshoring processes that predated them (Gylling et al., 2015). This implicitly denies the view of reshoring as one of the steps in the internationalization strategy of firms and possibly undermines a deep comprehension of this phenomenon.

Our paper sought to fill this gap of extant literature by analysing and classifying the principal motivations that led to offshoring and then to reshoring production.

We started by performing a content-based literature review (Seuring and Gold, 2012) of offshoring and reshoring motivations. This allowed us to identify 21 offshoring and 43 reshoring motivations and to classify them according to Fratocchi et al.'s (2016) theory-grounded framework based on the company's goals (i.e., increasing customer perceived value vs. improving cost-efficiency), and on the predominant factors affecting the decision (internal to the company vs. relating to the external environment).

Due to the lack of an established theory on reshoring, we then employed the inductive multiple case study methodology and analysed a sample of four Italian companies competing in traditional sectors of the economy (footwear, fashion, and travel gear / accessories) for which the "Made in" is likely to represent an important element.

The results of each case study were presented, focusing on the company background, the offshoring decision, the reshoring decision, and present situation (i.e., following the implementation of reshoring). Offshoring and reshoring motivations were highlighted and classified according to the aforementioned Fratocchi et al.'s (2016) framework.

Based on cross case analyses, we then proposed nine observations encompassing three key aspects of offshoring and reshoring decisions: Why (i.e., the "nature" of offshoring/reshoring drivers); How (i.e., the offshoring and reshoring governance modes); and Where (i.e., the geographical locations).

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References are available upon request.

SERVITIZATION AND DYNAMIC CAPABILITIES: AN EXPLORATORY REVIEW AND RESEARCH AGENDA

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Abstract

One of the main challenges for firms nowadays is to faces market changes through a manufacturing trend named Servitization, or the increased offerings of packages of products and services to add value to core product offerings. Firms facing servitization need to reconfigure their processes and capabilities to develop more and better services, achieving a sustained competitive advantage and enhancing firm performance in the process. These reconfiguring and transformation processes can be considered as enablers of underlying components of dynamic capabilities. This fact primarily suggests a close connection between servitization and dynamic capabilities view. This paper aims to analyze the servitization and dynamic capabilities theoretical underpinnings proposing potential value from the relationship. In this study, we develop an exploratory review of empirical papers on servitization in order to research the link between underlying components of dynamic capabilities (sensing, seizing and reconfiguring capability) and the implementation of a servitization strategy. Our analysis supports this initial suspected connection. However, sensing and reconfiguring capabilities seems to be the most promoted underlying components in servitized firms. According to this find, we propose a research agenda with the aim of developing additional studies grounded to the link found between the Dynamic capabilities view and the process of servitization.

Keywords: Servitization, dynamic capabilities, reconfiguring capabilities

Introduction

During the last three decades, scholars have shown a sustained interest in understanding how firms create value by adding services to products (Cusumano et al., 2015). Since Vandermerwe and Rada (1988) introduced the term servitization to refer this phenomenon, some theorists have attempted to develop conceptual models and reviews in order to help researchers to face the research challenges of the field (see e. g. Quinn et al., 1990; Oliva and Kallenberg, 2003; Baines et al., 2009; Baines et al., 2015). In addition, great efforts have been devoted to response research questions, specially through cases studies (see e. g. Finne et al., 2003; Raja et al., 2010; Bandinelli and Gamberi, 2012; Laine et al., 2012; Baines and Lightfoot, 2013; Smith et al., 2014).

Nowadays, many companies are transforming themselves from goods-dominant into service-dominant logic companies in order to gain a competitive advantage (Vargo and Lusch, 2004; 2008). Even it is widely claimed that such competitive advantage achieved through services is often more sustainable due to its labor dependence and the major difficulty to be imitated (Baines et al., 2009). However, despite the growing interest to understand how servitization can become a source of sustainable competitive advantage, few studies have provided empirical evidence which guide practitioners to implement a servitization strategy. Many unresolved questions remain about how organizations design the service or trigger and leader the required organizational transformation.

The connection between servitization and sustainable competitive advantage points out that the servitization strategy could be explained through the lens of Dynamic Capabilities view (Teece et al., 1997). In this theoretical approach, scholars have attempted to explain how firms achieved a sustainable competitive advantage through specific dynamic capabilities (DCs henceforth) such as, new product development and alliance management capability (see e. g.: Barrales-Molina et al., 2014; Pavlou and ElSawy, 2011; Schilke, 2014; Vanpoucke et al., 2014). These real DCs can be explained through three underlying processes (sensing, seizing and reconfiguring) which granted their dynamic nature (Teece, 2007). Some previous papers have suggested an initial link between both theoretical frameworks (see e.g.: Fisher et al., 2010; Kindström et al, 2013), but the research advances are still insufficient to explain how connect these approaches. On the one hand, DCs view has traditionally adopted product-oriented business logic, devoting few efforts to explain DCs nature of service firms. On the other hand, research on servitization is still focused on building theory and achieving solidity in findings of empirical papers (Baines and Lightfoot, 2013).

In this study we develop an exploratory review of recent empirical papers on servitization to analyze how firms which successfully implement a servitization strategy are able to create the underlying processes of DCs. This review allows us to identify which mechanisms are implemented in servitized firms to trigger DCs and propose a research agenda to advance in the connection of both theoretical frameworks. Therefore, the aim of this paper is twofold. First, we want to explore the relationship between servitization and DCs, and second, we pursue to guide future studies focused on how servitized firms achieve a sustainable competitive advantage.

Literature review

Servitization

Vandermerwe and Rada (1988) define servitization as an increment in the entire market package of customer focused combinations of products, services and knowledge offered by a firm searching for additional value to their base product offerings. They propose three reasons a firm may servitize: to give additional value to preferred customers; to prevent competitors from entering a market; and to gain differentiation. In order to give additional value, new value propositions are generated for customers through product-oriented and customer's process-oriented services (Kujala et al., 2010). This changes the patterns of value realization away from a goods-centric focus where value is realised in exchange, towards a service value orientation (Vargo and Lush, 2004).

Firms offering product and services have changed the competitive landscape through a process of refocusing specialized resources to support their product in service. Based on the competitive advantage generic strategies established by Porter (1979) the concept of servitization is linked to firm differentiation obtained by knowing the requirements of a customer base and creating barriers to entry through adding services which enable products to be differentiated. Whilst firms may servitize due to strategic rationale, literature also shows economic and environmental rationales for firms to go downstream and capture value from adding services (Wise and Baumgartner, 1999). Even when servitization attempt to obtain a better competitive position to increase the flow of revenues (Martinez et al., 2010), a lot of the literature of the topic is focused on the difficulties of managerial decision-making and strategy-formation associated to the process.

Dynamic Capabilities

Teece et al., (1997) defined a dynamic capability as a firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing market circumstances. After their initial contribution, several scholars have reflected on the double meaning of the phrase "dynamic capabilities" (e. g.: Ambrosini and Bowman, 2009; Loasby, 2010). On the one hand, the word "capability" refers to a persistent and repeated pattern of behavior to achieve a constant performance in any organizational activity. On the other hand, the adjective "dynamic" allows to clarify their main role, which is to ensure the renewal of the stock of resources and capabilities. Consistently, according to Zollo and Winter (2002), dynamic capabilities are learned and stable patterns of collective activity through which the organization systematically modifies its operating routines. In this sense, the "capability" implies regularity in performance, which leads to consider dynamic capabilities as a superior organizational routine that impact upon resources and routines (Barrales-Molina et al., 2015; Winter, 2003; Loasby, 2010).

Some scholars have tried to achieve more precise definitions of DCs and for this, have proposed specific processes and capabilities that can be seen as real DCs. In particular, new product development and alliance management capability are recognized in the field as the most consolidated examples of DCs (Barrales-Molina et al., 2013; Schilke, 2014). With this approach, it may be easier to shed light on the generalized nature of dynamic capabilities and furthermore, researchers count with empirical bases and major management applicability. In addition, Teece (2007) divided DCs into three underlying capabilities, which embody their dynamic nature: sensing, seizing and reconfiguring capabilities. This approach have been quite helpful to the field in order to define the components that any organization or to develop to generate DCs. Recently, Helfat and Peteraf (2014) have extended this theoretical framework proposing that these underlying capabilities can be extrapolated to managerial individual level. These contributions pursue to explain the microfoundations of DCs through the components, which embody these outstanding capabilities.

Servitization and microfoundations of DCs

To provide a comprehensive review of the recent empirical papers in servitization, we conducted an exploratory search of the SCOPUS database. With the aim of analyzing the most rigorous empirical studies, we limited our survey to journals indexed in JCR. We selected empirical articles that included the word "servitization" in title or abstract[2]. Our search ultimately retrieved 21 articles. For analysis of the collection of studies, we employed the microfoundation perspective of DCs and studied if findings of these empirical papers suggested the generation of the underlying capability of DCs: sensing, seizing or reconfiguring. Our main goal is to analyze the prospective link between servitization these underlying capabilities, and therefore, to be able to explain how servitizied firms can achieve sustainable competitive advantage through the lens of DCs view. The summary of our review is detailed in Appendix 1, where we have distinguished which underlying capabilities could have been created according the result of each empirical study.

Sensing capability in servitized firms

Sensing is the managerial ability to gather new market intelligence to detect new threats and opportunities (Teece, 2007). Servitization requires a strong customer centricity, as well as market orientation which provides valuable contacts opportunities to understand the customer needs and preferences (Baines et al., 2015). This statement is consistent with the findings of our analysis. The majority of empirical papers have found that servitized firms are able to successfully identify new threats and opportunities related to customers, suppliers and competitors. For instance, personnel of service delivery can identify if customer is satisfied with products and related services or on the contrary, his/her recent experiences are damaging his/her holistic perception of company image (Nenonen et al., 2014). Consistently, Baines and Lightfoot (2013) found that servitization leads firms to deliver services at the point the customer uses it, and this location ensures valuable communication about how products are used and perform. Subsequently, the study carried out by Bustinza et al. (2013) adds empirical evidence to the importance of integrating customers in supply chains of servitized firms. In other words, servitization enables firms to gain deeper insights into what customer value and lead to identify new opportunities based on customer value creation (Smith et al., 2014). Even, some sectors characterized by low sensing capabilities to indentify customer needs (such as magazine markets), use new media technologies to integrate customer in future designs and new applications (Viljakainen and Toivonen, 2014). Frequently, this sensing capability is enhanced through some mechanisms such as information and communication technologies (Baines and Lightfoot, 2013; Ljungquist, 2014), business games (Laine et al., 2012), collaboration legal contracts (Bastl et al., 2012) to name but a few mechanisms. Nevertheless, the level of promotion of sensing capability is inevitably related to the servitization strategy implemented (Saccani et al., 2014); definitely, those servitization strategies which promote major interaction with customers and long term relationships, use a wide variety of mechanisms which lead to promote sensing capability.

[2] To adopt a more extensive criteria, we did additional searches including the term of 'service business model innovation' due to this form are being used by a stream of recent papers (e. g.: Visnjic et al., 2014).

Seizing capability in servitized firms

Once a new opportunity is sensed, seizing requires maintaining or improving technological competences and complementary assets and also, investing heavily in new particular assets and designs related to the specific opportunity. In this sense, seizing is defined as the strategic response which frequently leads organizations to make quick decisions to change their business models and develop combinative capabilities to benefit from both typical manufacturer competences and the softer skills associated with customer contact (Smith et al., 2014; Bustinza et al., 2015).

Revised empirical papers show some common actions of servitized firms to explain how they usually seize new opportunities. Firstly, the majority of considered case studies illustrate that information gathered through customer contact or information technologies is employed to improve on-going products designs or trigger new investments on new technologies (Smith et al., 2014; Baines et al., 2015). Frequently, this gathered information suggests changes in business models, commonly oriented to new service offerings (Bustinza et al., 2013). Secondly, many servitized firms design formal groups to analyze the real value of new opportunities (Bandinelli and Gamberi, 2012) or even, integrate stakeholders in business games to achieve consensus in key decisions (Smith et al., 2014). Some of these groups are named ‘pilot projects’ and pursue to evaluate new risks, develop routines for quick tactical decisions or fix prices for new services. Finally, greater attention is paid to develop combinative capabilities. Many empirical studies demonstrate the presence of complementary and reciprocal dynamics on the level of product and service sales in servitized firms (see e. g.: Kastalli and Van Looy, 2013). In other words, servitized firms have to be able to combine products and services related capabilities to seize new opportunities (Smith et al., 2014). In this sense, outsourcing is one of the main mechanisms employed to achieve skills both manufacturing and service business (Baines and Lightfoot, 2013) and customer proximity can enhance these complementary dynamics between product and service skills (Kastalli and Van Looy, 2013).

Reconfiguration capability in servitized firms

Reconfiguring leads organizations to more flexible forms based on decentralisation, co-especialization or knowledge transfers between functional units. In this sense, many empirical studies on servitization show valuable findings that demonstrate how firms reconfigure themselves to change their business models toward service offerings. On the one hand, tasks, processes or structures are transformed due to the servitization process. According to Baines and Lightfoot (2013), the process of servitization frequently demands innovations in the way people are organized and skilled. For instance, Smith et al. (2014) explain how new customer value propositions were built into the design of task processes, becoming more oriented around individual expertise and less amenable to a structured or mechanistic design. Also, Baines and Lightfoot (2013) demonstrated that four successful servitized firms developed micro-vertical integration and strong inter-organizational relationships to ensure control over responsiveness and continuous improvements; even this integration is extended to supplier relationships. This result is consistent to the study developed by Bikfalvi et al. (2013) which proves a positive relationship between servitization and networking. On the other hand, more subtle and gradual changes in organizational culture and employee mindset are needed (Neely, 2008). Accordingly, many empirical studies are focused on explaining how firms move from a manufacturing culture to the values and rules needed to deliver high quality services. These new values are related to flexible working, committed behavior or resilient to the stressed due to ambiguity and uncertainty in the environment (Baines et al., 2015). Consistently, Viljakainen and Toivonen (2014) illustrate how magazine firms have had to change their culture to offer more frequent issues, be more creative or trigger trial and errors in their magazine designs. In this sense, Raja et al. (2010) highlight the valuable role of human resource function and business partnering to involve employees in servitization strategy and change their mindset focused on manufacturing skills.

Findings and research agenda derived from the review

Findings of the review

The review we summarize in Appendix 1 shows the latent connections we have appreciated between servitization and underlying capabilities of DCs. In some cases, empirical papers are focused in any dimension of servitization that indirectly emphasizes an unique underlying capability of DCs (e. g.: Kastalli and Van Looy, 2013; Nenonen et al., 2014; Benedettini et al., 2015; Raddats et al., 2015). However, other empirical papers which explain successful cases of servitization are valuable examples to explain how these firms has been able to develop indirectly the three underlying capabilities simultaneously (see e. g.: Fisher et al., 2010; Laine et al., 2012; Smith et al., 2014). Notwithstanding, we should emphasize that the promotion of sensing and reconfiguring components is more easily appreciable in the reviewed articles. In this sense, firms that have initiated a strategic change toward to the implementation of servitization, make important investments in mechanisms to gather information from customers and service collaborators, as well as, to leader structural and cultural changes to implement the new strategy. However, less attention has been paid to the set of managerial decisions made to seize opportunities sensed and understand the new business models resulted from servitization strategies. Ultimately, our review points out the necessity of a deeper explanation of which variables are included in new business models of firms which pretend to exploit products and their complementary services.

Nevertheless, in varying degrees, the connection between servitization and DCs is appreciable in the description of the implementation of a servitization strategy. Indeed, this latent connection is demonstrated through a wide variety of common practical mechanisms which firms employ to implement the servitization strategy. Despite authors can use different terms to refer these mechanisms, it is appreciable that firms use common vehicles to sense, seize and reconfigure in the same way that DCs view propose (Teece, 2007). Table 1 summarizes the set of mechanisms we have identified through this exploratory review.

Table 1 – Mechanisms used by Servitized Firms for Sensing, Seizing and Reconfiguring

Sensing capability	Legal contracts with service suppliers ▪ Information and communication technologies ▪ Information – gathering routines ▪ Information – processing technologies ▪ Customer collaboration plans ▪ Alliances with competitors ▪ Benchmark activities ▪ Value – cocreation mechanisms ▪ Location ▪ Business games to integrate customers ▪ Crossfunctional research groups
Seizing capability	▪ Business model innovation ▪ Routines for quick tactical decisions ▪ Fixing prices for new services mechanisms ▪ Business games to integrate stakeholders ▪ Pilot projects ▪ Combinative capabilities
Reconfiguring capability	▪ Microvertical integration ▪ Networking ▪ New task and structures design ▪ Reducing managerial jerarquies ▪ Promoting service culture ▪ Business partnering ▪ New hiring policies ▪ Rotating people between functional areas ▪ Fostering tryal and error practices

Research agenda

Once we have detected this latent connection between servitization and DCs, we can propose a set of research propositions which pursue to establish a more explicit connection between both research fields. Several arguments can serve to highlight the value of this connection. One the one hand, servitization research can base on DCs view to find a valid theoretical framework to explain its competitive value as strategy. On the other hand, DCs view can find in servitization research extremely valuable examples of products firms which respond to their environments with new value proposals with the aim of surviving the huge competitive pressure from their industries. To address these questions, we propose three guidelines that servitization research could follow to approach the strategic framework which DCs poses.

Servitization – sustainable competitive advantage

Some scholars have suggested that servitization strategy can lead products firms to achieve sustainable competitive advantage (Baines et al., 2009; Bustinza et al., 2015; Cusumano et al., 2015). In this sense, DCs view (see Teece, 2007) explains that to achieve this purpose, firms need to develop three underlying capabilities (sensing, seizing and reconfiguring). Our exploratory review has found that servitized firms commonly employ mechanisms to enhance these capabilities. In fact, some cases of failure in servitization can be explained through problems to develop properly some of these capabilities. For instance, Benedettini et al. (2015) demonstrated that higher bankruptcy risks in servitization are related to the inability of firms to reconfigure their structure, politics and culture. Also, Nenonen et al. (2014) found that when collaboration strategy has not been defined properly in business models of servitized firms, it is highly risky to seize the opportunities that complement services offer, due to the problem of image reputation that could arise. Consistently, Neely (2008) explained the servitization paradox through a set of challenges which servitization strategy posits to product firms which can be argued in terms of inability to sense customer demands, to seize opportunities and design business models which exploit combination of resources properly; and finally, to reconfigure mindsets related to marketing and sales processes, culture and risks.

Beyond this initial connection we have identified, we think that both success and failure of servitization strategy could be explained directly through the development of these underlying capabilities. Consequently, the link between servitization and sustainable competitive advantage would be argued in a deeper way, which also could show the path to exploit satisfactorily the servitization strategy. To achieve this, empirical framework adopted by some papers contributing to DCs view (see e. g.: Gebauer, 2011; Pavlou and El Sawy 2011; Jantunen et al., 2012), could be employed to explain in which degree, successful cases of servitization show a balanced combination of sensing, seizing and reconfiguring capabilities. In an equivalent way, it could be interesting to understand which lack of capabilities is common in failure cases. Definitely, using this empirical approach it could be provable if the successful implementation of the servitization strategy leads product firms to develop DCs.

Servitization – external context

The connection between servitization strategy and DCs view as valid theoretical framework has been argued through our exploratory review. Such interaction can serve to explain how the servitization strategy leads firms to achieve sustainable competitive advantage. However, explaining the servitization strategy through the lens of DCs would not make sense if the influence of competitive environment is not considered. To date, the majority of studies have focused on analyzing the required capabilities to implement successfully the servitization strategy. Then, the internal context of the strategy attracts the main interest from the field. For instance, scholars pay attention to structural and infrastructural dimensions (see e. g.: Baines and Lightfoot, 2013), relational capabilities (see e. g.: Bastl et al., 2012; Bikfalvi et al., 2013) or resource configurations (Bustinza et al., 2015) of servitized firms. Even, when empirical papers are framing in a specific industry, the role and the influence of this external context is not analyzed as a key factor to the strategy success (see e. g. Bandinelli and Gamberi, 2012). Notwithstanding, it is noticeable a recent stream of papers which address their attention to external factors as additional causes to consider in the servitization paradox. For instance, Benedettini et al. (2015) test some hypotheses related to the increasing level of risk that servitized firms face due to globalization, regulation changes, competititors, or demand trends. In addition, it is remarkable the contribution made by Cusumano et al. (2015), proposing a contingent approach to select a specific type of servitization according to the evolution of the industry. In this sense, future empirical papers could explain how sensing, seizing and reconfiguring capabilities are means to manage this external context.

Servitization – business model decisions

The servitization strategy leads firms to renew their business models (Kastalli and Van Looy, 2013; Visnjic et al., 2014). In fact, new business models will reflect which concrete choices are made to implement the servitization strategy (Casadesus-Masanell and Ricart, 2010; DaSilva and Trkman, 2014). Consistently, understanding which variables are included[3] in the resulting models, as well as the connections between them, will help us to understand how servitized firms are seizing opportunities related to servitization. Both, new business models are an additional evidence to understand that a servitized firm has developed successfully DCs (DaSilva and Trkman, 2014). Designing new business models requires that several variables fit together, pursuing desirable complementarities among activities, which suggest that managers of the firm show cognitive skills to develop DCs (Helfat and Peteraf, 2014).

To date, empirical papers have focused indirectly in explaining how servitized firms defined specific variables of their new business models. Specifically, many studies pay attention to the mechanism to design the new value proposition derived the combination of tangible products and services (see e. g.: Bandinelli and Gamberi, 2012; Laine et al., 2012; Smith et al., 2014; Viljakainen and Toivonen, 2014; Baines et al., 2015). Notwithstanding, designing successful business models to seize opportunities and responding emerging threats require understanding the underlying logic and the connection between all the relevant variables included in the resulting business models. In particular, with respect of servitization strategy, important connections come into play among variables such as new required core competencies, partner network, new cost structure or revenue model). In this sense, the fit or misfit between these variables should be considered as another crucial piece to include in the the conversation on the servitization paradox (see e. g. Neely, 2008; Benedettini et al., 2015). Recently, some empirical papers seem to point in this direction. For instance, Visnjic et al. (2014) compare the profitability derived from different business models that can be adopted by servitized firms. Then, for the time being, it is accepted that many business models can be proper to manage a servitization strategy, despite the key variables and their links are still underexplored in the field. Consequently, an additional effort in the successful business models of servitized firms would help to understand better how seizing capability is enhanced as a foundation of DCs.

Conclusions

Basing on the connection between servitization and sustainable competitive advantage, we have developed an exploratory review to analyze if servitization strategy could be explained through the basis of DCs view. In this review, we have found that in many cases, servitized firms are able to put into practice the underlying capabilities needed to achieve DCs (sensing, seizing and reconfiguring capabilities). Then, servitized firms can be considered a valuable sample of firms to illustrate the DCs generation.

Consequently, the interaction between servitization strategy and DCs view presents interesting opportunities which would enrich both research fields. Notwithstanding, a more strategic approach would be advisable to design future empirical papers on servitization. Firstly, analyzing the influence of the external context could shed light on the servitization paradox. And secondly, understanding the key factors of business models in servitized firms would allow to describe which choices are made to implement the servitization strategy.

[3] Scholars have made important effort to idenfity the variables included in business models. For example, Osterwalder et al. (2005) describe nine variable to be taken into account (value proposition, target customer, distribution channel, relationship, value configuration, core competencies, partner network, cost structure, revenue model)

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APPENDIX 1

Authors	Journal	Description of the empirical study	Sensing capability	Seizing capability	Reconfiguring capability
Baines and Shi (2015)	Product, Planning and Control	A Delphi research methology is applied to understand how 33 senior executives in 28 different organization have developed the process of servitization.	X		X
Benedettini, Neely and Swink (2015)	International Journal of Operations and Production Management	The study analyzes data from 129 bankrupt manufacturers to explore the impact of servitization strategy om bankruptcy risks.			X
Bustinza, Bigdeli, Baines and (2015)	Research-Technology Management	The study presents results from 102 senior executives in multinational companies. Findings show that organizational structure and position in value chain affect the success of servitization strategy.			X
Raddats, Burton and Ashman (2015)	Journal of Service Management	Data from 155 UK-based manufacturers are employed to identify key factors explaining success of servitization strategy.			X
Baines and Lightfood (2014)	International Journal of Operations and Production Management	A case study of 4 successful companies in servitization. Results show a set of key factors which develop these firms to deliver advanced services	X		
Nenonen, Ahvennienmi and Martinsuo (2014)	The Service Industries Journal	A case study conducted in two companies in the engineering industry. The results shows the role that company image plays in customer's selection of service providers	X		
Saccani, Visintin and Rapaccini (2014)	International Journal of Production Economics	The work develops a multiple case study to analyse the relationships between manufacturers and the suppliers when service delivery is outsourced.	X		
Smith, Maull and Ng (2014)	International Journal of Operations and Production Management	An in-depth case study of an organization considered to be exemplar in terms of servitization. Findings show that product service transition cannot be treated as discrete stages but is evolutionary and requires complex systems perspective.	X	X	X
Viljakainen and Toivonen (2014)	Futures	The study analyzes industrial changes in magazien markets derived from servitization. The work identifies seven trends in the contexts such as, dispersing customer base, changes in media use habits, and erosion of product business.	X		X
Visnjic, Wiengarten and Neely (2014)	Journal of Product Innovation Management	Results from 133 servitized firms show that the interplay between servitization and product innovation provide long-term performance benefits while can result in a degree of short-term performance sacrifice.		X	
Bustinza, Parry and Vendrell-Herrero (2013)	Supply Chain Management	Empirical analysis based on responses from 4.227 resindent music consumers in the UK. Results reveals the role of the customer and market orientation to create new value	X	X	
Finne, Brax and Holmström (2013)	Service Business	This study uses the case of Xerox to analyze how the environment also forces companies to develop a reversed servitization path.	X		
Kastalli and Van Looy (2013)	Journal of Operations Management	Empirical study conducted in sales-and-service subsidiaries of a large multinational equipment manufacturer. Findings reveal the value of costumer proximity to enhance product sales			X
Bandinelli and Gamberi (2012)	Journal of Manufacturing Technology Management	This work uses the case study method to illustrate how firms in oil and gas sector implement a Product-Service System strategy.	X	X	
Bastl, Johnson, Lightfoot and Evans (2012)	International Journal of Operations and Production Management	The authors develop a case study approach to examine the byer-supplier relationship in servitized context.	X		
Laine,	Managing Service	A longitudinal case study at a manufacturer firm which	X	X	X

Paranko and Suomala (2012)	Quality	shows that information exchange with customer is one of the most common outcomes of a servitization strategy			
Lin and Lin (2012)	Service Business	The study explores how Taiwanese firms implement a servitization strategy. Findings show that external factors such as industry competition or cooperation help to implement the strategy.			
Baines, Lightfoot and Smart (2011)	Journal of Manufacturing Technology Management	The authors develop a cross-sectional study of four companies to analyze how these firms implement vertical integration practices when face the challenge of servitization			X
Fisher, Gebauer, Gregory, Ren and Fleisch (2010)	Journal of Service Management	A multiple-case study is developed to seek dynamic capabilities created in servitized firms. Findings suggest dynamic capabilities differ between several approaches and predict which way a company chooses.	X	X	X
Raja, Green and Leiringer (2010)	Human Resource Management Journal	An exploratory case study to illustrate the HR challenges associated with servitization.			X
Neely (2008)	Operations Management Research	This work analyzes data from OSIRIS database on 10,028 firms to present empirical evidence about hidden risk associated with servitization		X	X

MONITORING AND CONTROLLING THE PROCESS QUALITY FOR MULTISTAGE MANUFACTURING SYSTEMS

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Abstract
The Study aims to develop a new control chart model suitable for monitoring the process quality of multistage manufacturing systems. Considering both the autocorrelated process outputs and the correlation occurring between neighboring stages in a multistage manufacturing system, we first propose a new multiple linear regression model to describe their relationship. Then, the multistage residual EWMA and CUSUM control charts are used to monitor the overall process quality of multistage systems. Moreover, an overall run length (ORL) concept is adopted to compare the detecting performance for various multistage residual control charts. Finally, a numerical example with oxide thickness measurements of a three-stage silicon wafer manufacturing process is given to demonstrate the usefulness of our proposed multistage residual control charts in the Phase II monitoring.

Keywords: Multistage system, Residual EWMA control chart, Residual CUSUM control chart.

Introduction
With the advent of modern technology, manufacturing processes have become rather sophisticated. Most manufacturing industries require several stages/steps to complete their final products, such as semiconductor, printed circuit board, chemical and telecommunication manufacturing processes. Recently, multistage process monitoring and controlling has become an important research issue, especially for the cases in which the process output are autocorrelated.

Traditional statistical process control chart (SPC) control charts merely focus on monitoring the quality characteristics of a single stage manufacturing process. Among them, exponentially weighted moving average (EWMA) and cumulative sum (CUSUM) control charts are proved to be more efficient than Shewhart chart for detecting the small sustained shift in the process mean. On the other hand, residual EWMA and residual CUSUM control charts (see Lu and Reynolds, 1999, 2001 for details) have been shown to be more suitable for monitoring the autocorrelated processes, which are commonly occurred in the above high-technology manufacturing industries. However, a suitable control chart for monitoring and controlling the process quality of multistage systems with autocorrelated observations is still lacking. Thus, it becomes necessary to develop a new control chart model suitable for monitoring the quality characteristic of multistage manufacturing systems.

The use of control charts generally involves Phase I and Phase II. In the Phase I study, the parameters of the process is estimated based on a set of historical data and used to establish control limits for the Phase II monitoring. In the Phase II monitoring, the data are sequentially collected over time to assess whether the parameters of the process have changed from the estimated values in the Phase I study. In this paper, focusing on Phase II study, a new multiple regression model for multistage manufacturing processes is developed by considering the effect of correlation between the neighboring stages and the residual EWMA and CUSUM control charts for each stage can be constructed accordingly. Then, we propose a new Overall Run Length (ORL) for evaluating the overall detecting ability of new control chars for multistage manufacturing systems. In addition, the cumulative density function (CDF) of ORL is derived and its correctness has also been confirmed. Subsequently, a simulation study is conducted to explore various combination of control parameters for multistage residual control charts when the average of Overall In-Control Run Length (AOIRL) is fixed at 370 (i.e. we fix the type I error rate of the overall multistage system at 0.27%). Once the

AOIRL is fixed at 370, the average of Overall Out-of-Control Run Length (AOORL) is used to evaluate the detecting ability of multistage residual control charts when the multistage system is out of control. Furthermore, a sensitivity analysis is performed to explore the effect of AOORL on the detecting ability of multistage residual control charts when the number of stage increases. Finally, a numerical example with oxide thickness measurements of a three-stage silicon wafer manufacturing process is used to illustrate the usefulness of our proposed multistage residual control charts in the Phase II monitoring.

Literature review

Monitoring the process quality for multistage systems

In multistage manufacturing system, the quality characteristics of interest are often highly dependent. To monitor and diagnose multistage manufacturing system, (Zhang, 1984, 1987, 1990 & 1992) proposed the Cause-Selecting Charts (CSCs). The advantage of this method is that once an out-of-control signal or a special cause occurs in the process, it can effectively distinguish which stage/subprocess is out of control.

To monitor quality of a process with multivariate variables, (Hawkins, 1991) proposed Shewhart and cumulative sum control charts based on regression-adjusted variables. He further proposed the concept of group charts. (Tsung and Xiang, 2004) proposed Group EWMA Chart with One-Step Forecasting Errors (OFSE) combining quality characteristics from multistage manufacturing system into a single stage control statistic. The control statistic is defined as:

$$MZ_j = max_{1\le k\le N}\left(\left|Z_{k,j}\right|\right) \qquad (1)$$

where $Z_{k,j}$ is the EWMA statistics of jth OFSE. Even though this control statistics combine the multistage control charts into a single stage control chart, it doesn't preserve the structure of CSCs and thus loses the advantage of using CSCs. Moreover, it is not easy to trace back to the root stage where the subprocess is out of control.

(Yang and Yang, 2006) considered a two-step process in which the observations X in the first step can be modeled as an AR(1) model and the observations in the second step Y can be modeled as a transfer function of X. The AR(1) model they used can be written as:

$$X_t = (1-\phi)\xi_X + \phi X_{t-1} + a_t, t = 1,2,\ldots \qquad (2)$$

where ξ_X is the process mean of the first step, ϕ is the autoregressive parameter satisfying $\phi < 1$ and a_t are assumed to be independent normal random variables with mean 0 and variance σ_a^2. The transfer function to express the relationship between X and Y is:

$$Y_t = C_Y + V_0 X_t + V_1 X_{t-1} + N_t, t = 1,2,\ldots \qquad (3)$$

where C_Y is a constant and N_ts are independent normal random variables with mean 0 and variance σ_N^2. Without loss of the generality, this study used AR(1) model to develop a new control chart suitable for monitoring the process quality of multistage manufacturing systems. Instead of using Shewhart control charts, residual EWMA and residual CUSUM control charts are adopted for monitoring the small sustained shift in autocorrelated processes.

Residual-based EWMA control chart

(Lu and Reynolds, 1999) proposed a residual-based EWMA control chart for monitoring the mean of process in which the observations can be described as an ARMA(1,1) model. The residual of

ARMA(1,1) model can be expressed as:

$$e_k = X_k - \xi_0 - \phi(X_{k-1} - \xi_0) + \theta e_{k-1}, \qquad (4)$$

where ξ_0 is the process mean, ϕ is the autoregressive parameter and θ is the moving average parameter. The control statistics of the residual EWMA control chart is defined as:

$$R_k = (1 - \lambda)R_{k-1} + \lambda e_k \qquad (5)$$

where λ is smoothing constant and e_k the residual.

(Lu and Reynolds, 1999) assessed the performance of observation-based and residual-based EWMA control charts respectively when dealing with autocorrelated observations. It was found that their performances were fairly close when monitoring low or medium autocorrelated process. But, for a highly autocorrelated process, the residual EWMA control chart is more effective in detecting a process mean shift.

Residual-based CUSUM control chart

(Lu and Reynolds, 2001) introduced a two-sided residual CUSUM control chart whose control statistics is defined as:

$$CR_k^+ = max\{0, CR_{k-1}^+ + (e_k - r\sigma_e)\},$$
$$CR_k^- = max\{0, CR_{k-1}^- - (e_k + r\sigma_e)\} \qquad (6)$$

where r is reference value, $CR_0^+ = CR_0^- = 0$. If control statistic CR_k^+ or CR_k^- exceeds $\pm c\sigma_e$, then control charts sends out warning signal. (Lu and Reynolds, 2001) further assessed the performance of residual-based CUSUM control chart when dealing with autocorrelated observations. It was found that the residual-based CUSUM control chart has similar performance with residual-based EWMA control chart proposed by (Lu and Reynolds, 2001).

(Asadzadeh *et al.*, 2012) proposed a regression-adjusted CUSUM control chart and two conditional expected values based EWMA control charts. Their proposed control charts can be applied to multistage manufacturing processes (MMPs) and multistage service operations (MSOs), such as survivability measures in healthcare services. (Asadzadeh *et al.*, 2013) developed a cause-selecting CUSUM control chart based on proportional hazard model and binary frailty model. Moreover, (Asadzadeh *et al.*, 2013) revised proportional hazard model to handle autocorreltion within observations and proposed one CUSUM and two EWMA control charts. The other type of EWMA control chart can be referred to (Yang *et al.*, 2011) in which they proposed a nonparametric version of the EWMA Sign chart without assuming a process distribution.

Methodology for developing multistage residual control charts

(Yang and Yang, 2006) considered a two-step process in which the observations X in the first step can be modeled as an AR(1) model and observations in the second step Y can be modeled as a transfer function of X. However, they did not take the autocorrelation of Y_t into account when constructing multistage system models. In this section, a new multiple regression model for multistage manufacturing processes is developed by considering both the autocorrelated process outputs and the correlation occurring between the neighboring stages. Then, the residual EWMA and CUSUM control charts for each stage can be constructed accordingly.

The structure of multistage system model

Let $Y_{i,j}$ be the process variable for jth sample from i^{th} stage. The structure of our proposed multistage system model can be shown in Fig. 1:

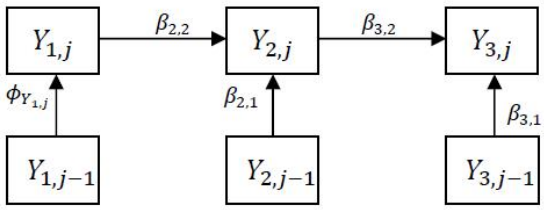


Figure 1 - Structure of multistage system model

since AR(1) model is a commonly used time series for autocorrelated data, the 1st stage data can be fitted with the following AR(1) time series model:

$$Y_{1,j} = (1-\phi)\xi_{Y_{1,0}} + \phi Y_{1,j-1} + \varepsilon_{1,j}, j = 1,2,\ldots \qquad (7)$$

where $Y_{1,j}$ is the process variable for jth sample from 1st stage, $Y_{1,j-1}$ is the process variable for $(j-1)\ th$ sample from the 1st stage, $\xi_{Y_{1,0}}$ is the process mean of the 1st stage, ϕ is the autoregressive parameter and $\varepsilon_{1,j}$ is assumed to be an independent normal random variable with mean 0 and variance $\sigma^2_{\varepsilon_1}$. Then, the estimated time series model can be expressed as $\hat{Y}_{1,j} = \left(1-\hat{\phi}\right)\xi_{Y_{1,0}} + \hat{\phi}Y_{1,j-1}$ and the residual of the jth sample from the 1st stage is defined as $e_{Y_{1,j}} = Y_{1,j} - \hat{Y}_{1,j}$. Starting from the 2nd stage, the process variable from each stage of multistage system can be fitted with a multiple regression model as written below,

$$\begin{cases} Y_{2,j} = \beta_{2,0} + \beta_{2,1}Y_{2,j-1} + \beta_{2,2}Y_{1,j} + \varepsilon_{2,j}, j = 1,2,\ldots \\ Y_{3,j} = \beta_{3,0} + \beta_{3,1}Y_{3,j-1} + \beta_{3,2}Y_{2,j} + \varepsilon_{3,j}, j = 1,2,\ldots \\ \vdots \\ Y_{\mathrm{W}-1,j} = \beta_{\mathrm{W}-1,0} + \beta_{\mathrm{W}-1,1}Y_{\mathrm{W}-1,j-1} + \beta_{\mathrm{W}-1,2}Y_{\mathrm{W}-2,j} + \varepsilon_{\mathrm{W}-1,j}, j = 1,2,\ldots \\ Y_{\mathrm{W},j} = \beta_{\mathrm{W},0} + \beta_{\mathrm{W},1}Y_{\mathrm{W},j-1} + \beta_{\mathrm{W},2}Y_{\mathrm{W}-1,j} + \varepsilon_{\mathrm{W},j}, j = 1,2,\ldots \end{cases} \qquad (8)$$

where $Y_{i,j}$ is the process variable for jth sample from ith stage and $Y_{i,j-1}$ is the process variable for $(j-1)th$ sample from ith stage. $\beta_{i,0}$ is a constant, $i = 2,\ldots,\mathrm{W}$. $\varepsilon_{i,j}$ is assumed to be an independent normal random variable with mean 0 and variance $\sigma^2_{\varepsilon_i}$, $i = 1,\ldots,\mathrm{W}$.

Hence, the least square estimator of process variable for jth sample from ith stage is given by

$$\hat{Y}_{i,j} = \hat{\beta}_{i,0} + \hat{\beta}_{i,1}Y_{i,j-1} + \hat{\beta}_{i,2}Y_{i-1,j}, i = 2,\ldots,\mathrm{W} \qquad (9)$$

and the residual of jth sample from ith stage is defined as $e_{Y_{i,j}} = Y_{i,j} - \hat{Y}_{i,j}$, $i = 2,\ldots,\mathrm{W}$ where $e_{Y_{i,j}}$ is assumed to be an independent normal random variable with mean 0 and variance $\sigma^2_{\varepsilon_i}$.

Multistage residual EWMA control chart

The control statistic for our proposed multistage residual EWMA control chart is defined as:

$$\begin{cases} Z_o = \mu_{e_{Y_{i,j}}},\ j = 0, i = 1,\ldots \mathrm{W} \\ Z_j = \lambda e_{Y_{i,j}} + (1-\lambda)Z_{j-1},\ j = 1,2,3\ldots, i = 1,\ldots,\mathrm{W} \end{cases} \qquad (10)$$

where $e_{Y_{i,j}}$ is residual of observation from ith stage, λ is smoothing constant, $0 < \lambda \leq 1$ and $\mu_{e_{Y_{i,j}}}$ is initial value. Then, the control statistic and control limits of residual EWMA control chart can be expressed as:

$$\begin{cases} \text{UCL} = Z_{e_{Y_{i,j}}} + L\sigma_{e_{Y_{i,j}}}\sqrt{\frac{\lambda}{(2-\lambda)}[1-(1-\lambda)^{2j}]} \\ \qquad\quad \text{contorl statistic} = Z_{e_{Y_{i,j}}} \\ \text{LCL} = Z_{e_{Y_{i,j}}} - L\sigma_{e_{Y_{i,j}}}\sqrt{\frac{\lambda}{(2-\lambda)}[1-(1-\lambda)^{2j}]} \end{cases} \qquad (11)$$

where L is control limit.

Multistage residual CUSUM control chart

The control statistic for our proposed multistage residual CUSUM control chart can be defined as:

$$CR^{+}_{e_{Y_{i,j}}} = max\left\{0, e_{Y_{i,j}} - k\sigma_{e_i} + CR^{+}_{e_{Y_{i,j-1}}}\right\},$$
$$CR^{-}_{e_{Y_{i,t}}} = max\left\{0, -k\sigma_{e_i} - e_{Y_{i,j}} + CR^{-}_{e_{Y_{i,j-1}}}\right\} \qquad (12)$$

where $e_{Y_{i,j}}$ is residual of observation from ith stage, $k\sigma_{e_i}$ is reference value, $CR^{+}_{e_{Y_{i,0}}} = CR^{-}_{e_{Y_{i,0}}} = 0$. If control statistic $CR^{+}_{e_{Y_{i,j}}}$ or $CR^{-}_{e_{Y_{i,j}}}$ exceeds decision limits$\pm h\sigma_{e_i}$, then CUSUM control chart will give the warning signals.

Criterion for evaluating detecting ability of multistage control charts

In this research, in order to early detect the process changes, we propose the Overall In-Control Run Length (OIRL) defined in equation (13) as a criterion for evaluating the overall detecting ability of multistage control charts when a multistage process is in control,

$$\text{OIRL} = min(IRL_1, IRL_2, IRL_3, \ldots, IRL_i), i \geq 1 \qquad (13)$$

where IRL_i represents the value of in-control run length of ith stage. When a multistage process is in control, we expect the average of OIRL≥370 so that type I error rate of overall multistage system can be maintained at $\alpha \leq 0.27\%$. Moreover, when a multistage process is out of control, we use the Overall Out-of-Control Run Length (OORL) defined in equation (14) as a criterion for evaluating the overall detecting ability of multistage control charts, i.e.

$$\text{OORL} = min(ORL_1, ORL_2, ORL_3, \ldots, ORL_i), i \geq 1 \qquad (14)$$

where ORL_i represents the value of out-of-control run length of ith stage.

Derivation of cumulative distribution function of Overall Run Length

Due to the fact that run length follows geometric distribution, we can assume that the run length of ith stage also follows geometric distribution with success probability α_i, denoted by $\text{Geo}(\alpha_i)$ and define the overall run length (*ORL*) as

$$\text{Y} = min(RL_1, RL_2, \ldots, RL_{\text{W}}), \qquad (15)$$

where $RL_i \sim \text{Geo}(\alpha_i),\ i = 1 \ldots, W$. The cumulative distribution function of *ORL* can be derived as below:

$$\begin{aligned}
\mathrm{P}(\mathrm{Y} \le \mathrm{y}) &= \mathrm{P}(min(RL_1, RL_2, \dots, RL_{\mathrm{W}}) \le \mathrm{y}) \\
&= 1 - \mathrm{P}(min(RL_1, RL_2, \dots, RL_{\mathrm{W}}) > y) \\
&= 1 - \mathrm{P}(RL_1 > y, RL_2 > y, \dots, RL_{\mathrm{W}} > y) \\
&= 1 - \textstyle\prod_{i=1}^{\mathrm{W}} \mathrm{P}(RL_i > y) \\
&= 1 - \textstyle\prod_{i=1}^{\mathrm{W}} [1 - \mathrm{P}(RL_i \le y)] \\
&= 1 - \textstyle\prod_{i=1}^{\mathrm{W}} \{1 - [1 - (1 - \alpha_i)^y]\} \\
&= 1 - \textstyle\prod_{i=1}^{\mathrm{W}} (1 - \alpha_i)^y \\
&= 1 - \left[\textstyle\prod_{i=1}^{\mathrm{W}} (1 - \alpha_i)\right]^y \qquad (16)
\end{aligned}$$

If we let $\prod_{i=1}^{\mathrm{W}}(1-\alpha_i) = 1 - \alpha^*$, then $\mathrm{P}(\mathrm{Y} \le \mathrm{y}) = 1 - (1 - \alpha^*)^y$, where $\alpha^* = 1 - \prod_{i=1}^{\mathrm{W}}(1-\alpha_i)$. It is proven that ORL follows a geometric distribution with success probability α^*. In practice, if we assume that type I error rate for each stage are equal, then the type I error of the overall system can be obtained:

$$\alpha^* = 1 - (1 - \alpha)^{\mathrm{W}} \qquad (17)$$

Hence, if we set the overall type I error rate is α^* and divided it into W stages, then the corrected type I error rate α' for each stage can be obtained as:

$$\alpha' = 1 - (1 - \alpha^*)^{\frac{1}{\mathrm{W}}} \qquad (18)$$

Simulation results for multistage residual EWMA control charts

In our simulation studies, once the average of OIRL (AOIRL) is fixed at 370, the average of OORL (AOORL) is used to evaluate the detecting performance of multistage residual control charts with that of Phase II control charts after conducting 1000 simulation runs. Without loss of generality, we consider a multistage system with three stages and the sample size is set as 3000 for each stage. Moreover, the process variances for each stages are assumed to be homogeneous and the amount of process mean shift for each stage are also assumed to be the same when a multistage system is out of control. Based on the same setting of control parameter as shown in Lucas & Saccucci (1990), the AOIRL of our proposed multistage residual EWMA control chart using (λ, L)=(0.05, 2.615) equals 500 when the number of stage is set as $\mathrm{W} = 1$. The AOIRL of our proposed control chart equals 88.32 when the process mean shift is set to be $\delta = 0.25$. These two results are fairly closed to those given by (Lucas and Saccucci, 1990). Thus, the correctness of our computer simulation program is confirmed.

By fixing the AOIRL at 370, various combinations of control parameters for multistage residual EWMA control chart under different autocorrelations are listed in Table 1. Table 1 indicates that, for a given autocorrelation ϕ, the control limit L increases as the smoothing constant λ increases; for a given smoothing constant λ, the control limit L increases slightly as the autocorrelation ϕ increases.

Table 1 - Various combinations of control parameters (λ, L) for multistage residual EWMA control chart in which AOIRLs are close to 370 under different autocorrelations

AOIRL = 370	(λ, L)				
$\phi = 0.25$	(0.05, 2.91)	(0.10, 3.11)	(0.15, 3.16)	(0.20, 3.21)	(0.25, 3.24)
$\phi = 0.50$	(0.05, 2.94)	(0.10, 3.12)	(0.15, 3.17)	(0.20, 3.23)	(0.25, 3.25)
$\phi = 0.75$	(0.05, 2.98)	(0.10, 3.15)	(0.15, 3.19)	(0.20, 3.25)	(0.25, 3.27)

As AOORL is used to evaluate and compare the detecting ability of multistage residual control charts, simulation results of AOORLs for multistage residual EWMA control charts under various combinations of autocorrelations, control parameters and the process mean shifts are summarized in Table 2. For a given process mean shift and control parameter, AOORL increases as autocorrelation increases. The comparison results show that the detecting ability of multistage residual EWMA control chart performs better when the autocorrelation is small. Thus, it is suggested to choose a smaller smoothing constant for a process with high autocorrelation. For example, $\lambda = 0.03$ ($\lambda = 0.02$) is a better choice for smoothing constant as the autocorrelation $\phi = 0.5$ ($\phi = 0.75$). In addition, the optimal choice of smoothing constant is in the range $0.01 < \lambda \leq 0.05$ for a process with moderate or high autocorrelation.

Table 2 - Comparison of AOORLs for multistage residual EWMA control charts under various combinations of autocorrelations, control parameters and the process mean shifts δ

AOORL		δ			
	(λ, L)	0.25	0.50	0.75	1.00
$\phi = 0.25$	(0.05, 2.91)	56.88	5.40	1.12	1.00
	(0.10, 3.11)	96.27	18.98	4.04	1.31
	(0.15, 3.16)	118.29	28.82	7.71	2.53
	(0.20, 3.21)	146.82	40.22	12.70	4.65
	(0.25, 3.24)	165.13	48.66	16.39	6.40
$\phi = 0.50$	(0.03, 2.79)	78.01	8.90	1.31	1.00
	(0.05, 2.94)	118.95	25.48	4.88	1.36
	(0.10, 3.12)	180.32	54.29	17.69	6.27
	(0.15, 3.17)	196.25	69.40	27.00	11.24
	(0.20, 3.23)	237.28	89.15	38.16	17.32
	(0.25, 3.25)	244.64	103.69	49.30	23.18
$\phi = 0.75$	(0.02, 2.74)	207.11	54.47	12.24	3.09
	(0.03, 2.83)	228.25	78.75	29.24	8.65
	(0.05, 2.98)	264.71	117.42	52.20	25.25
	(0.10,3.15)	327.80	177.95	93.73	53.23
	(0.15,3.19)	310.68	191.59	111.03	69.71
	(0.20,3.25)	337.12	224.00	139.51	88.98
	(0.25,3.27)	335.02	236.75	157.49	103.93

Simulation results for multistage residual CUSUM control chart

By fixing the AOIRL at 370, various combinations of control parameters for CUSUM under different autocorrelations (ϕ=0.25, 0.5, 0.75) are listed in Table 3. Table 3 indicates that, for a given autocorrelation, the reference value (k) increases as decision limit (h) decrease. This result is consistent with the findings of (Hawkins, 1993). Moreover, for a given reference value, the decision limit is insensitive to the autocorrelation.

Table 3 - Various combinations of control parameters (h, k) for multistage residual CUSUM control charts in which AOIRLs are close to 370 under different autocorrelations

AOIRL=370	(h, k)			
$\phi = 0.25$	(15.5, 0.125)	(10.1, 0.250)	(7.39, 0.375)	(5.82, 0.500)
$\phi = 0.50$	(15.5, 0.125)	(10.1, 0.250)	(7.38, 0.375)	(5.84, 0.500)
$\phi = 0.75$	(15.5, 0.125)	(10.1, 0.250)	(7.41, 0.375)	(5.80, 0.500)

As AOORL is used to evaluate and compare the detecting ability of multistage residual control charts, the simulation results of AOORL s for multistage residual CUSUM control charts under various combinations of autocorrelations, control parameters and the process mean shifts are summarized in Table 4. Table 4 indicates that, for a given process mean shift and control parameter, AOORL for multistage residual CUSUM control chart increases as the autocorrelation increases. The comparison results show that the detecting ability of multistage residual CUSUM control chart performs better when the autocorrelation is small.

Table 4 - Comparison of AOORL s for multistage residual CUSUM control charts under various combinations of autocorrelations, control parameters and the process mean shiftsδ

		δ			
	(h, k)	0.25	0.50	0.75	1.00
ϕ = 0.25	(15.5, 0.125)	**80.67**	38.85	25.61	19.24
	(10.1, 0.250)	88.75	**32.87**	19.53	14.02
	(7.39, 0.375)	130.47	37.54	**17.50**	11.85
	(5.82, 0.500)	213.83	84.14	17.68	**11.04**
ϕ = 0.50	(15.5, 0.125)	**126.36**	58.20	37.78	28.37
	(10.1, 0.250)	146.51	**55.82**	31.82	22.04
	(7.38, 0.375)	192.78	80.85	**32.48**	19.97
	(5.84, 0.500)	261.31	141.37	36.70	**20.93**
ϕ = 0.75	(15.5, 0.125)	**231.52**	122.51	80.28	58.65
	(10.1, 0.250)	283.71	**151.22**	85.24	56.89
	(7.41, 0.375)	308.19	201.50	**104.42**	63.74
	(5.80, 0.500)	367.19	293.34	119.54	**74.51**

Note that the bold figures indicate the reference value k is set as half of half of process mean shift δ

Sensitivity analysis

Due to the fact that the number of stages within a multistage systems increase will cause the type I error of the overall multistage system increases as well. Thus, given the type I error of the overall multistage system is fixed at 0.27%, a sensitivity analysis is performed to explore the change in control parameters as the number of stages increases.

The AOORL values of multistage residual EWMA control chart under various combinations of autocorrelations, control parameters, the number of stages and the process mean shifts are shown in Table 5. For a given mean shift and number of stages, the AOORL value increases as autocorrelation increases. For a given mean shift and autocorrelation, the AOORL value decreases as the number of stages increases. Based on the simulation results shown in Table 5, we can conclude that the detecting ability of proposed multistage residual EWMA control chart increases as the number of stages increases.

Table 5 - The AOORL value of multistage residual EWMA control chart under various combinations of autocorrelation, control parameters, the number of stage and the process mean shift

AOORL			δ			
	(λ, L)	W Stages	0.25	0.50	0.75	1.00
ϕ = 0.25	(0.10, 3.11)	W = 3	96.27	18.98	4.04	1.31
	(0.10, 3.25)	W = 5	75.38	11.75	2.16	1.08
	(0.10, 3.35)	W = 7	67.83	9.89	1.85	1.02
ϕ = 0.50	(0.10, 3.12)	W = 3	180.32	54.29	17.69	6.27
	(0.10, 3.25)	W = 5	144.02	39.73	12.19	4.03
	(0.10, 3.35)	W = 7	136.27	34.10	9.94	3.04
ϕ = 0.75	(0.10, 3.15)	W = 3	327.80	177.95	93.73	53.23
	(0.10, 3.28)	W = 5	306.92	152.53	80.64	41.37

(0.10, 3.39)	W = 7	304.54	148.44	76.18	38.58

The effects of the number of stages on detecting ability of various multistage residual CUSUM control charts are listed in Table 6. For a given ϕ, the AOORL value decreases as the number of stages increases. This means that the detecting ability of multistage residual CUSUM control chart increases as the number of stage increases.

Table 6 - The AOORL value of multistage residual CUSUM control chart under various combinations of correlation, control parameters and the number of stage if the process mean is $\delta = 1$

AOORL			δ
ϕ	(h, k)	W Stages	1.00
	(5.82, 0.50)	W = 3	11.04
$\phi = 0.25$	(6.25, 0.50)	W = 5	10.20
	(6.65, 0.50)	W = 7	9.77
	(5.84, 0.50)	W = 3	20.93
$\phi = 0.50$	(6.25, 0.50)	W = 5	17.65
	(6.65, 0.50)	W = 7	17.00
	(5.80, 0.50)	W = 3	74.51
$\phi = 0.75$	(6.25, 0.50)	W = 5	61.59
	(6.64, 0.50)	W = 7	59.87

Numerical example

To demonstrate the practical application of our proposed multistage residual control charts, the data set provided by (Montgomery, 2008) with thirty (30) oxide thickness measurements taken in the Phase II monitoring of a silicon wafer manufacturing process is used for illustration purpose. In this numerical example, we treat different time frames as different stages (i.e. three different time frames can be viewed as a special case of three-stage system) and the control limits at different stages are set as the same in the Phase II monitoring. Moreover, we only use one point outside control limits as the detecting rule at different stages and the out-of-control points will be removed from the process subsequently.

Comparison between Phase II EWMA and multistage residual EWMA control charts

In this example, the Phase II EWMA and multistage residual EWMA control charts using control parameter (λ, L)=(0.2, 3.21) are shown in Fig. 2 and Fig. 3 respectively if the process mean shift is set as $\delta = 0.50$. As one can see from Fig. 2, the Phase II EWMA control charts cannot detect the mean shift until 3rd stage and the OORL value is 27. On the other hand, if the process mean shift is set as $\delta = 0.50$, the multistage residual EWMA control chart using control parameter (λ, L)=(0.20, 3.21) is able to detect this mean shift at 1st stage and the OORL value is 6 (see Fig. 3). The comparison results show that the detecting ability of our proposed multistage residual EWMA control chart outperforms that of the Phase II EWMA control chart.

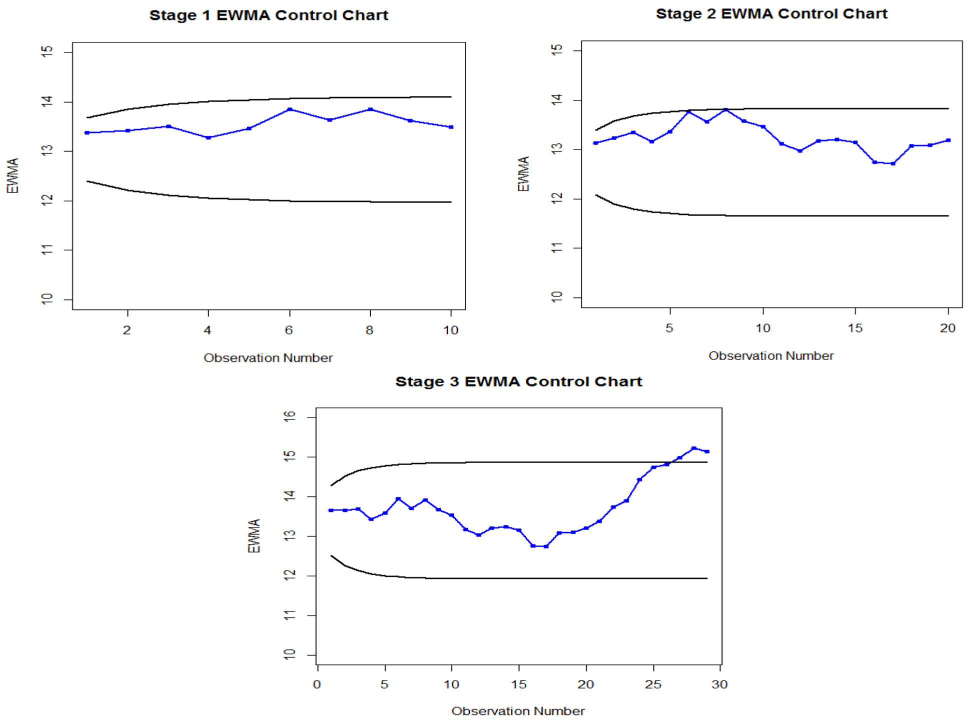


Figure 2 - The Phase II EWMA control charts using control parameter (λ, L)*=(0.2, 3.21) if the process mean shift is set as* $\delta = 0.50$.

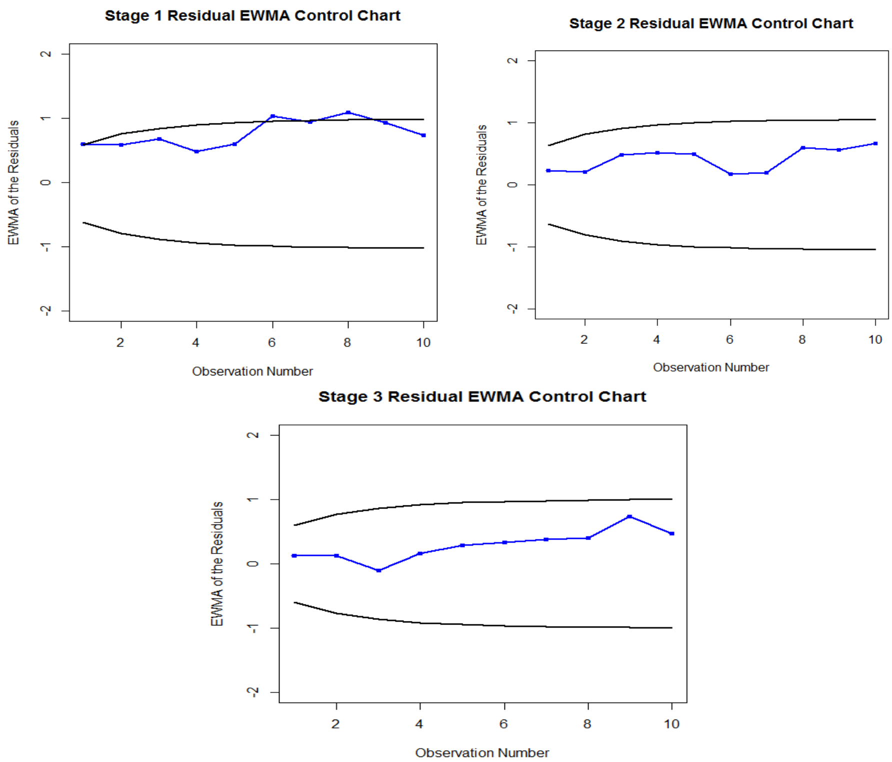


Figure 3 - The multistage residual EWMA control charts using control parameter (λ, L)*=(0.2, 3.21) if the process mean shift is set as* $\delta = 0.50$.

The comparison results of OORLs for the Phase II and multistage residual EWMA control charts under various mean shifts are summarized in Table 7. Table 7 indicates that, if the process mean shift is set as $\delta = 0.25$, the Phase II EWMA control chart using control parameter (λ, L)=(0.10, 3.11) cannot detect this mean. On the other hand, if the process mean shift is $\delta = 0.25$, the multistage residual EWMA control chart using control parameter (λ, L)=(0.10, 3.11) is able to detect this mean shift at 1st stage. Moreover, if the process mean shift is set as $\delta = 0.25$, the multistage residual EWMA control chart using control parameter (λ, L)=(0.05, 2.91) and (0.10, 3.11) are able to detect the mean shift at 1st stage. Although the Phase II EWMA control chart using control parameter (λ, L)=(0.05, 2.91) can detect the mean shift at 1st stage, the EWMA control chart using control parameter (λ, L)=(0.10, 3.11) cannot detect the mean shift. Also, it is worth noting that our proposed multistage residual control charts have the advantage of using cause-selecting charts which preserve the property of diagnosability. Hence, the detecting ability of our proposed EWMA control charts outperform that of the Phase II EWMA control charts.

Table 7 - Comparison between the Phase II EWMA and Multistage Residual EWMA Control charts under various mean shift (δ)

		δ			
		0.25	0.50	0.75	1.00
Phase II EWMA	(λ, L) (0.05, 2.91)	1(I*)	1(I*)	1(I*)	1(I*)
	(λ, L) (0.10, 3.11)	--	1(I*)	1(I*)	1(I*)
	(λ, L) (0.15, 3.16)	28(III*)	6(II*)	1(I*)	1(I*)
	(λ, L) (0.20, 3.21)	28(III*)	27(III*)	1(I*)	1(I*)
	(λ, L) (0.25, 3.24)	28(III*)	27(III*)	1(II*)	1(I*)
Multistage EWMA	(λ, L) (0.05, 2.91)	1(I*)	1(I*)	1(I*)	1(I*)
	(λ, L) (0.10, 3.11)	1(I*)	1(I*)	1(I*)	1(I*)
	(λ, L) (0.15, 3.16)	--	1(I*)	1(I*)	1(I*)
	(λ, L) (0.20, 3.21)	--	6(I*)	1(I*)	1(I*)
	(λ, L) (0.25, 3.24)	--	6(I*)	1(I*)	1(I*)

Note: (I) indicates that multistage control chart can detect the mean shift at 1st stage.*

Comparison between Phase II CUSUM and multistage residual CUSUM control charts

The Phase II CUSUM control charts using control parameter (h, k)=(5.82, 0.50) are shown as in Fig. 4 when the process mean shift is set as $\delta = 1.00$. As shown in Fig. 4, the Phase II CUSUM control chart cannot detect the mean shift until 2nd stage. The OORL value is 8.

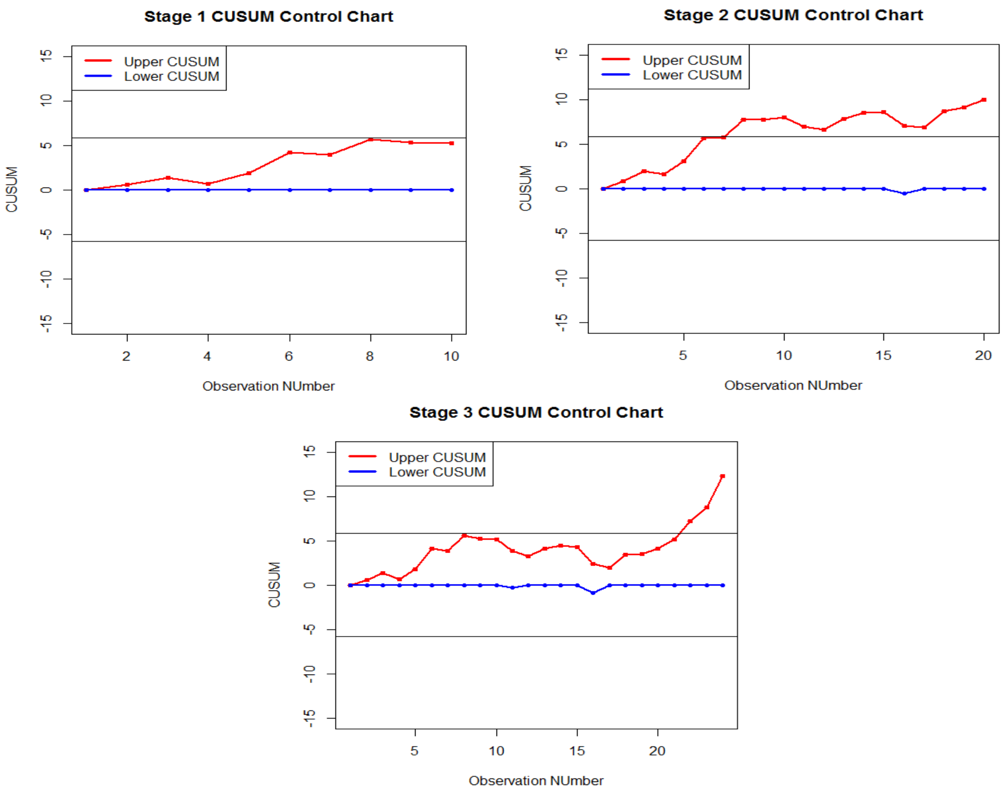
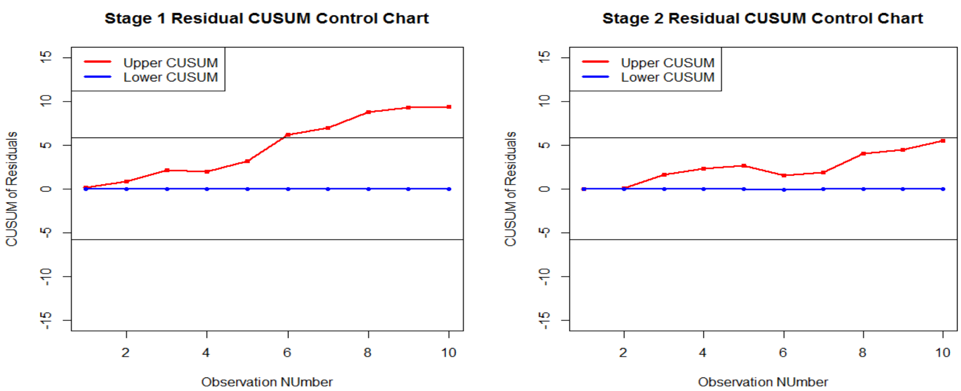


Figure 4 - The Phase II CUSUM using control parameter (h, k)*=(5.82, 0.50) when the process mean shift is set as* $\delta = 1.00$

If the process mean shift is set as $\delta = 1.00$, the multistage residual CUSUM control chart using the same control parameter is shown in Fig. 5. Note that the multistage residual CUSUM control chart will be able to detect this mean shift at 1st stage and the OORL value is 6.



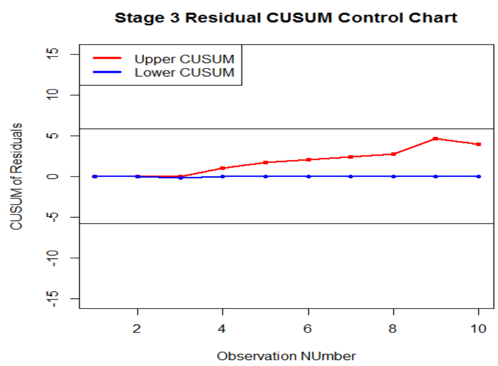


Figure 5 - The multistage residual CUSUM control chart using control parameter (h,k)*=(5.82, 0.50) if the process mean shift is set as* $\delta = 1.00$

In addition, the comparison results of OORLs for the Phase II and multistage residual CUSUM control charts under various process mean shifts are summarized in Table 8. Note that, if the process mean shift is set as $\delta = 0.75$, the multistage residual CUSUM control chart is able to detect the mean shift at 1st stage (OORL = 9), whereas the Phase II CUSUM control chart cannot detect the mean shift until 2nd stage (OORL = 20). Based on the comparison results shown in Table 7 and 8, we can conclude that the detecting ability of our proposed multistage residual EWMA and CUSUM control charts outperform that of the Phase II EWMA and CUSUM control charts. Moreover, our proposed multistage residual control charts have the advantage of using cause-selecting charts which preserve the property of diagonosibility. Hence, the detecting ability of our proposed control charts outperform that of the Phase II control charts.

Table 8 - Comparison of OORLs between the Phase II CUSUM and Multistage Residual CUSUM Control charts under various mean shifts (δ*)*

		δ			
		0.25	0.50	0.75	1.00
Phase II CUSUM	(h,k)	(15.5, 0.125)	(10.1, 0.25)	(7,39, 0.375)	(5.82, 0.50)
		--	--	20(II*)	8(II*)
multistage CUSUM	(h,k)	(15.5, 0.125)	(10.1, 0.25)	(7.39, 0.375)	(5.82, 0.50)
		--	--	9(I*)	6(I*)

Note: (I) indicates that multistage control chart can detect the mean shift at 1st stage.*

Conclusions and discussions

Considering both the autocorrelated process outputs and the correlation occurring between neighboring stages, we have successfully developed a new multiple regression model for multistage manufacturing systems. Then, the residual EWMA and CUSUM control charts for each stage are constructed accordingly. An Overall Run Length (ORL) concept is adopted as the criterion for evaluating the detecting ability of multistage control charts. The simulation results show that the detecting ability performs better when the autocorrelation is smaller for multistage residual EWMA and CUSUM control charts. The cumulative distribution function (CDF) of ORL is further derived to confirm the correctness of ORL. Finally, a numerical example further illustrates that the detecting ability of our proposed multistage residual EWMA and CUSUM control charts outperform that of the Phase II EWMA and CUSUM control charts respectively. Note that the process variances for each stages are assumed to be homogeneous and the amount of process mean shift for each stage are also assumed to be the same when a multistage system is out of control. These assumptions may be lifted in the future studies. In this paper, the process data for each stage are assumed to be stationary and follow AR(1) time series model. Future studies should consider the cases for non-stationary time series and profile data. Similar research can be further extended to develop multivariate residual MEWMA and MCUSUM control charts for multistage manufacturing systems.

The proposed multistage residual control charts can also be extended to the quality surveillance of other multistage systems as the multistage residual EWMA and CUSUM control charts have the advantage of using cause-selecting charts which preserve the property of diagonosibility. In contrast with the quality surveillance using the Phase II control charts, one can effectively distinguish a special cause occurs in a particular stage and thus provides diagnostic information regarding which stage is out-of-control. Hopefully, the results of this research may provide a useful guideline for quality practitioners when monitoring and controlling the process quality for multistage manufacturing systems with autocorrelated data in the Phase II monitoring.

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THE IMPACT OF IT PLATFORMS ON MANAGEMENT EDUCATION USING THE CASE METHOD

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Abstract

Information technology (IT) has become rapidly accepted as a complement or substitute of the traditional learning setting, hence challenging the mode of teaching among Management scholars. This research examines the impact of IT platforms on Management education using the case method. We theorize that internal IT platforms may enable instructors to engage students to increase learning performance, which in turn leads to a greater student satisfaction, and external IT platforms (i.e., social media for teaching activities) may amplify the relationships between internal IT platforms, student engagement, learning performance, and student satisfaction. Using the variance-structural equation modeling technique, and the partial least squares method of estimation on a combination of survey and secondary data from 94 Spanish students from a Management course, the empirical analysis gives support to our theory. The incremental contributions of this paper to research on Information Systems and Management Learning, and its educational implications are also discussed.

Keywords: IT platforms, student engagement, learning performance, student satisfaction

Introduction

Information technology (IT) is changing the way firms and individuals operate and interact (Benitez and Walczuch, 2012). The mode of teaching and interacting with students is changing dramatically with the expansion of Internet as a way to deliver course content (Brower, 2003). In an increasingly digital environment, Management scholars have the challenge to discover what IT resources use and how to leverage these IT resources to improve student learning and satisfaction. IT platforms (i.e., an example of IT resources) are becoming rapidly accepted to complement the traditional (i.e., face-to-face) classroom/teaching.

Prior Information Systems (IS) and Management Learning literature has mainly focused on opinion and discussion pieces describing student motivation (Arenas et al., 2012; Campbell, 2000), student expectations (Ma et al., 2000), or learning quality (Piccoli et al., 2000; Redpath, 2012) acquired from online learning compared with traditional learning. A few exceptions have studied the impact of student's interaction and collaboration in interactive IT platforms (e.g., discussion forums, wikis) on student learning outputs (Arbaugh and Benbunan, 2007; Daspit and D'Souza, 2012; Kane and Fichman, 2009). Arbaugh and Benbunan (2007) examine the effects of different types of participant interactions on perceived learning and satisfaction in online courses. They found that perceived learning is associated with student-instructor and student-system interactions, while perceived satisfaction is associated with greater student-student and student-system interactions. The opinion piece of Kane and Fichman (2009) discuss that wikis can be used as collaborative platforms to create and exploit collaborative content for teaching activities.

To the best of our knowledge, little has been studied about the role of different IT platforms (i.e., internal and external) on blended learning Management education in the case method context. Brower (2003) conceptually argues that discussion forums may be useful in Management online learning using the case method. Specifically, she ends up with three key instructor practices that can help online forums to emulate a face-to-face classroom discussion. Our study tries to go further by theorizing and empirically analyzing the effect of different IT platforms (i.e., internal and external) on the student learning performance and satisfaction in a face-to-face Management course using the case method.

On the other hand, prior Management Learning literature has focused on explaining the antecedents of the students learning output (i.e., learning performance, student satisfaction). While some studies consider interactivity (among students, and among students and the instructor) and social capital as antecedents of perceived learning and student satisfaction (Arbaugh and Benbunan, 2007; Lu et al., 2013), surprisingly, any prior study has explored the relationship between learning performance and student satisfaction. Our study tries to shed light on this relationship.

Prior IS research has classified IT-based media in conventional and social media (Braojos et al., 2015a; Luo et al., 2013). We draw on these studies to differentiate two types of IT platforms that may be potentially used in Management education: internal and external IT platforms. Internal IT platforms are more conventional, less interactive, and provided internally by the Business School (e.g., Moodle-based learning platform, e-mail, instructor's web site). External IT platforms refer to external social media such as Facebook, Twitter, and YouTube, which are highly interactive and very popular among our students.

We examine the impact of internal and external IT platforms on Management education using the case method. Our central thesis is that internal IT platforms may enable instructors to engage students to increase student learning performance, which in turn leads to a greater student satisfaction. We theorize that external IT platforms may amplify the relationships between internal IT platforms, student engagement, learning performance, and student satisfaction. The theory is tested using the variance-based structural equation modeling (SEM) technique and the partial least squares (PLS) method of estimation on a sample of 94 undergraduate Spanish students from a Management course using the case method.

Theory and hypotheses

The community of inquiry framework describes how complementary factors (teaching presence, social presence, and cognitive presence) enable student learning in online environments. Teaching presence refers to the instructor's ability to facilitate discourse, engage in interactions and direct instructions. Social presence refers to the perception of openness and communication that facilitates interpersonal communications (interactions between student-student and instructor-student). Cognitive presence denotes the student's ability to absorb and create new knowledge (Redpath, 2012). We draw from the community of inquiry framework to theoretically explain the complementary role of external IT platforms in the relationships between internal IT platforms, student engagement, and learning performance.

The uses and gratifications framework is a model of user choice of new information technologies which evaluates the user (e.g., customer, student, and instructor) motivation to use IT such as Internet (Stafford et al., 2004), virtual environments (Nambisan and Baron, 2009) or web-based information services (Luo et al., 2011). Users made IT usage decisions based on the perceived gratifications/benefits they can gain from that usage (Braojos et al., 2015a). This framework identifies four motivators to use IT: cognitive (benefits come from knowledge acquisition), social integrative (benefits derive from user ties with others), personal integrative (gains in reputation and status), and hedonic/affective (enjoyment and pleasurable experiences). Student's perception of these four types of benefits can shape their involvement and satisfaction with the course through the usage of IT platforms. We draw from this framework to link internal IT platforms and student engagement, and to theoretically explain the potential moderating effects of external IT platforms on our proposed model.

Internal IT platforms and student engagement

Internal IT platforms are the information technologies that afford students to be connected with the course in everywhere and at any time (Liaw and Huang, 2002; Piccoli et al., 2000). They are more conventional, less interactive, and are provided internally by the Business School (e.g., Moodle-based learning platform, e-mail, instructor's web site) with the main goal to facilitate the communication between instructor and students. Student engagement refers to the degree of emotional commitment, motivation, and involvement of a student to collaborate, participate, and contribute during the course activities (Arbaugh and Benbunan, 2007).

The usage of internal IT platforms as a complement of traditional classroom setting may enable a greater student engagement in the course. First, the instructor may use internal IT platforms to provide the course syllabus and teaching material, and update the course information to the students (i.e., teaching presence). Students are more able to be engaged in the course if teaching material is provided beforehand by internal IT platforms (Taras et al., 2013; Yang et al., 2007), and they receive critical information on the course in an agile way through IT (Brower, 2003).

Second, internal IT platforms are suitable tools to organize the teaching material or to quickly solve doubts about the course (e.g., by email). Students can positively evaluate these instructor efforts in providing teaching materials in a structured way, or quickly solving doubts through internal IT platforms. This positive evaluation may make students to become more willing to participate and collaborate in the learning process. For example, Moodle-based learning platforms and the instructor web site are suitable tools for students to access to the course contents. Finally, web technologies provide students with more learning flexibility to work from home at their own pace (Bretz and Johnson, 2000; Liaw and Huang, 2002). Keeping in touch with the instructor by internal IT platforms such as the e-mail or the instructor web site at any time and any place provide the student with a greater flexibility and freedom. This flexibility is viewed by students as a benefit in effectively managing time, which provokes a greater autonomy and responsibility for their own learning to increase student engagement (Campbell, 2000). We therefore hypothesize:

Hypothesis 1 (H1): There is a positive relationship between internal IT platforms and student engagement.

Student engagement and learning performance

Learning performance refers to the extent to which students achieve the course learning goals in terms of knowledge acquisition, understanding key concepts, and developing managerial skills (Alavi et al., 1997). Student engagement may increase learning performance. As long as the student feels a sense of commitment with the learning process, their knowledge assimilation can improve. First, engaged students are more able to collaborate and create new experiences in class, which can improve their knowledge acquisition (Hwang and Francesco, 2010). Motivated students can explore, construct, and absorb higher levels of learning in the way they feel part of the learning process (Daspit and D'Souza, 2012).

Second, motivated students can obtain better learning performance because the Pygmalion effect (Armstrong et al., 2004). In general, motivated students want to make the most of the course; hence, students' previous belief that they can get a superior learning can be effectively fulfilled at the end of the course (i.e., Pygmalion effect) (Crossan et al., 2013). Finally, a greater control of the students over the learning activities can improve their learning performance (Piccoli et al., 2000; Redpath, 2012). When students are involved in the course, they can improve their learning outcomes (Schiller et al., 2013). For example, with the case method students have the opportunity to face decision-making processes, hence feeling part of the process of learning, which enhances student engagement to increase learning performance. We hypothesize that:

Hypothesis 2 (H2): There is a positive relationship between student engagement and learning performance.

Learning performance and student satisfaction

Student satisfaction refers to the degree in which the student expectations on the instructor, course, and teaching method are met. Learning performance may increase student satisfaction. Students with better learning outcomes may feel a positive affection toward the instructor, who can be seen as a critical agent in their learning process (Chiu et al., 2007). The student satisfaction with the course design and teaching method may be derived from the extent the student had assimilated knowledge, understood critical management concepts, and learned to identify central topics, make managerial decisions and solve key business problems. Therefore, it is rational to expect that:

Hypothesis 3 (H3): There is a positive relationship between learning performance and student satisfaction.

The amplifier role of external IT platforms in the relationship between internal IT platforms and student engagement

External IT platforms are social and interactive platforms referring to external (i.e., non-created by the Business School) information technologies. External IT platforms refer to social media platforms for teaching activities in the context of the course (e.g., Facebook, Twitter, Pinterest, LinkedIn, Google +) (Daspit and D'Souza, 2012; Kane and Fichman, 2009). These social media can be used by firms for business activities, by individuals for enjoyment, and by instructors and students for teaching/learning activities (Braojos et al., 2015a).

We argue that in presence of external IT platforms, the relationship between internal IT platforms and student engagement can be stronger, that is, external IT platforms can perform an amplifier role. Based on the community of inquiry framework, we argue that external IT platforms contain functionalities that allow instructors to facilitate discussion forums and create an environment of social interaction among students (Daspit and D'Souza, 2012). Certainly, these superior functionalities enabled by external IT platforms, increases the opportunity to leverage internal IT platforms to create a sense of commitment among students to be part of the learning process.

Drawn from the uses and gratifications framework, students can engage in external IT platforms motivated by cognitive, social integrative, personal integrative, and hedonic perceived benefits (Stafford et al., 2004). External IT platforms (i.e., social media for teaching activities) are more user-friendly, flexible, agile, newer, and closer to the students as compared with internal IT platforms. Students can complementary use external IT platforms, in addition to internal IT platforms, for a variety of reasons. In this sense, Facebook or WhatsApp are efficient tools to informally communicate and get last minute information from other students. External IT platforms can be used for different purposes in comparison with internal IT platforms. For example, Twitter can be used by the instructor to run some additional questions in advance to the case discussion in class. Similarly, Twitter can be used to recognize the best in class on the case discussion. Thus, students can use external IT platforms to stay informed about the course activities and because the conception of group they perceived on the platform (Shen et al., 2013). Hence, student engagement enabled by internal IT platforms can be stronger when the instructor also uses external IT tools in the course. Then, it is rational to expect that internal and external IT platforms can be complementary to achieve student engagement:

Hypothesis 4 (H4): External IT platforms positively amplify the relationship between internal IT platforms and student engagement.

The amplifier role of external IT platforms in the relationship between student engagement and learning performance

We argue that the relationship between student engagement and learning performance can also be amplified by external IT platforms. Drawn from the community of inquiry framework, social interrelatedness enabled by external IT platforms may promote student collaborative learning in online environments in the way students freely express their opinions and experiences (Brower, 2003; Daspit and D'Souza, 2012; Taras et al., 2013). Learning happens when instructors and students can confront different points of view, exchange, share, and integrate knowledge (Brower, 2003). Interactive technologies such as social media engage more students in the learning process as they enable a higher monitoring of student progress (Arenas et al., 2012), which may lead to a greater learning performance. Hence, the student engagement effect on learning performance can be positively amplified in presence of external IT platforms. In a course using the case method, the instructor can engage students in the learning process by providing key interesting cases (e.g., Benihana of Tokyo, Earl 2004). In addition, the instructor can provide students with additional material about the case's firm (e.g., videos related to the firm's operations) via social media (e.g., Facebook, Twitter, YouTube) with the aim to become students familiar with the firm. For example, because it is very difficult that a student of Spain (or other countries) can imagine the operations of Benihana if he/she has not visited the restaurant, the instructor can provide via YouTube the Benihana profile video (e.g., https://www.youtube.com/watch?feature=player_embedded&v=epoIPgQrAyQ). In that way, the instructor brings students closer to the firm, hence reinforcing their motivation in the learning process.

Based on the uses and gratifications framework, external IT platforms may provide a useful and enjoyable environment that encourages students interact with others in the learning community (Yoon et al., 2014). For example, instructors can use Second Life (a social media platform) to learn. When motivated students face the challenge to act in a real life situation (e.g., in Second Life), students can enjoy the experience and achieve stronger learning outcomes (Schiller et al., 2013), thus maximizing their learning performance based on their engagement.

External IT platforms are well suited tools to provide more thoughtful student comments, encourage shy students to participate and avoid monopolization of dominant/leader students (Brower, 2003; Redpath, 2012), something that may happen in some case discussion sessions. In this sense, engaged students may use external IT platforms as a second opportunity to participate in the virtual/social case discussion to improve their learning performance (Hwang and Francesco, 2010). For example, the instructor can use Twitter to run additional questions before/after the class discussion to give all the students the opportunity to participate. Based on this discussion, we hypothesize that:

Hypothesis 5 (H5): External IT platforms positively amplify the relationship between student engagement and learning performance.

The amplifier role of external IT platforms in the relationship between learning performance and student satisfaction

We also claim that in presence of external IT platforms, the relationship between learning performance and student satisfaction can be stronger, that is, external IT platforms may perform a positive amplifier role. External IT platforms enable a greater interaction among students and the instructor. Based on the uses and gratifications framework we argue that students may experiment socio-emotional benefits toward the online-learning community in the extent they experience less isolation in the learning process (Arbaugh and Benbunan, 2007; Arenas et al., 2012). Complex tasks are perceived easier with the support of the community (instructor and other students). Then, more interactions between student-student and instructor-student through external IT platforms may reinforce the student satisfaction generated through the learning (Arbaugh and Benbunan, 2007). External IT platforms are flexible tools considered as useful to solve doubts and save time, hence creating a positive attitude toward the course (Campbell, 2000). Moreover, with the usage of external IT platforms students can perceive a sense of belonging and enjoyment that can make students improve their satisfaction at the time they learn. Hence, student satisfaction generated through the learning can be stronger when external IT platforms are used:

Hypothesis 6 (H6): External IT platforms positively amplify the relationship between learning performance and student satisfaction.

Research methodology

Sample and data

The proposed model is tested based on a combination of survey and secondary data from 94 Spanish students from a Management course offered at the School of the authors. This course was taught using the lecturing combined with the case method. In addition, the instructor used several internal (e.g., teaching platform, email), and external IT platforms (e.g., Twitter, Skype, Pinterest) in the execution and development of the course to work and interact with the students.

First, we performed a brainstorming session with the students to obtain an overall understanding about the role of IT in the course. Then, we carefully designed a questionnaire, wherever possible, by adapting scales from prior research on IS and Management Learning. After that, the questionnaire, including a cover letter with instructions, was given to students in the last session of the course (in June 2015). Of the total of 156 students enrolled in the course (in three groups), the valid responses obtained came from 94 students, which it constitutes a response rate of 60.256%. This response rate can be considered as satisfactory since implies a response rate of about 90% of the students that actively and constantly attended to the course sessions, and is consistent with the response rates obtained in prior literature (e.g., Arbaugh and Benbunan, 2007). On average, the age of the respondent is 24 (S.D. = 4.951) with a range of 20 to 44, and a median of 22 years. 62% of the respondents are female.

Measures

Internal and external IT platforms are single constructs measured by adapting the scale of Lu et al. (2013). Internal IT platforms assess the extent to which students use internal IT platforms (internal teaching platform, email, instructor's web site, laptop) for teaching activities. External IT platforms assess the level of external social media platforms (Facebook, Twitter, Pinterest, LinkedIn, Google +) usage to execute course activities. The absence of a scale to measure student engagement led us to create our own measurement scale. We created a three new indicators scale to measure student engagement. We measure learning performance by adapting the scales of Alavi et al. (1997), and Daspit and D'Souza (2012). Student satisfaction is specified as a composite second-order construct determined by instructor satisfaction, course satisfaction, and teaching method satisfaction. Instructor satisfaction is a newly developed scale in the study. Course satisfaction is based in the scale of Arbaugh and Benbunan (2007). Teaching method satisfaction is measured by adapting the scales of Alavi et al. (1997), Arenas et al. (2012), and Daspit and D'Souza (2012). All constructs are specified as composite (Ajamieh et al., forthcoming). In composite constructs, composite measures (i.e., the ingredients) jointly contribute to the meaning of the construct (i.e., the concept) (Rigdon et al., 2014). Hence, composite measures are endogenous (the indicator causality is from indicators to the construct), and conceptually non-interchangeable (indicators do not have the same content) (Benitez and Ray, 2012; Braojos et al., 2015b).

The empirical analysis results may change as older students and students with low prior IT skills may be less pleased in the usage of IT. Students of different gender and with a prior perception toward the instructor may also determine the student satisfaction with the course. This study controls for student age, student gender, prior IT student skills, and instructor reputation (e.g., Arbaugh and Benbunan, 2007). We compute student age as the natural logarithm of the student's age (Chen et al., forthcoming), student gender as a dummy variable (0: Male, 1: Female), prior IT student skills as a two indicators scale that measures prior students skills in using IT (Arbaugh and Benbunan, 2007), and instructor reputation also as a two indicators scale that assess the perceived instructor reputation at the beginning of the course.

Empirical analysis

We use the variance-based SEM technique and the PLS method of estimation to test the hypotheses and to examine the mediation effects involved in the proposed model. PLS method of estimation is appropriate for the following reasons. First, PLS is a full-fledged SEM approach that can test for exact model fit (Henseler et al., 2016). Second, this method of estimation is particularly advisable in models that use composite constructs, as the proposed model (Chen et al., 2015, forthcoming; Wang et al., 2015). Finally, PLS is advisable when some constructs of the model use newly developed scales, as this study (Tiwana and Konsynski, 2010). We use the statistical software package Advanced Analysis for Composites (ADANCO) 2.0 Professional (http://www.composite-modeling.com/) (Henseler and Dijkstra, 2015). We use the bootstrapping algorithm with 5000 subsamples to estimate the level of significance of weights, loadings, and path coefficients.

Measurement model evaluation

We check for content validity, multicollinearity, weights, loadings, and their level of significance for the composite constructs (Benitez and Ray, 2012; Cenfetelli and Bassellier, 2009). We check the content validity of all the constructs included in our study, wherever possible, by using scales previously validated in prior research (Pavlou and El Sawy, 2006; Wang et al., 2015). After the data collection, we check for multicollinearity by calculating the indicator variance inflation factors (VIFs). The indicator VIFs for our constructs range from 1.016 to 3.757 well below the accepted threshold of 10, which it suggests that multicollinearity is not a problem in our constructs (Benitez and Ray, 2012; Benitez et al., 2015). After checking multicollinearity, a composite indicator should be retained when its weight is significant, or when its weight is not significant but loading it is (Petter et al., 2007). However, composite indicators/dimensions which weight and loading are non-significant can be retained at discretion of the author team to preserve the construct content validity (Benitez et al., 2015; Cenfetelli and Bassellier, 2009). The analysis yields some weights that are not significant and significant loadings at the 0.100 level. We also find that neither the weight nor the loading of one indicator of internal IT platforms construct referring to the use of the email is significant. We have decided to keep this indicator to preserve the content validity of the construct (Ajamieh et al., forthcoming).

Due to the fact that student satisfaction is a multidimensional construct we estimate our proposed model by performing the two steps approach (Chin, 2010). In a first step we freely correlate the single constructs and the dimensions of the multidimensional construct (i.e., instructor satisfaction, course satisfaction, and teaching method satisfaction) to obtain the latent variables scores of the dimensions. In the second step we use the latent variables scores as the manifest variables of the construct student satisfaction (Wang et al., 2015). Table A1 (in the appendix) provides detailed information on the measurement model properties.

Test of hypotheses

We perform a PLS estimation and analyze the effect size (f^2) for the hypothesized relationships to test the proposed research model. Thus, we examine the path coefficients, level of significance, R^2, and f^2 values to test the hypotheses. Path coefficients, their level of significance, and the R^2 values are individual measures of the structural quality and explanatory power of the model. Path coefficients around 0.200 are considered economically significant (Benitez and Ray, 2012). Main path coefficients in our model range from 0.193^{*} to 0.494^{***}, being significant at the 0.050 level. R^2 values higher than 0.200 indicate good explanatory power of the endogenous variables of the model (Chin, 2010). The R^2 values for the endogenous variables range from 0.176 to 0.815. The empirical analysis provides support for all our hypotheses at 0.050 level. Internal IT platforms enable instructors to engage students to increase student learning performance, which in turn leads to a greater student satisfaction. External IT platforms amplify the relationships between internal IT platforms, student engagement, learning performance, and student satisfaction. Related to the control variables, none of them has a significant effect on student satisfaction. Results are kept before and after including the control variables, which provides robustness to our analysis. Figure 1 shows the estimation of the proposed model.

The effect size specifies the relative size of each incremental relationship/link introduced in the model. f^2 values lower than 0.020, greater than 0.150, and greater than 0.350 indicate weak, medium, or large effect size of adding a link between an exogenous and endogenous variable (Cohen, 1988; Henseler and Fassott, 2010). The f^2 values involved in the hypothesized relationships range from 0.037 to 0.475. Table 1 shows the analysis of the effect size for every relationship in the model. Overall, this analysis suggests good explanatory power for the proposed model.

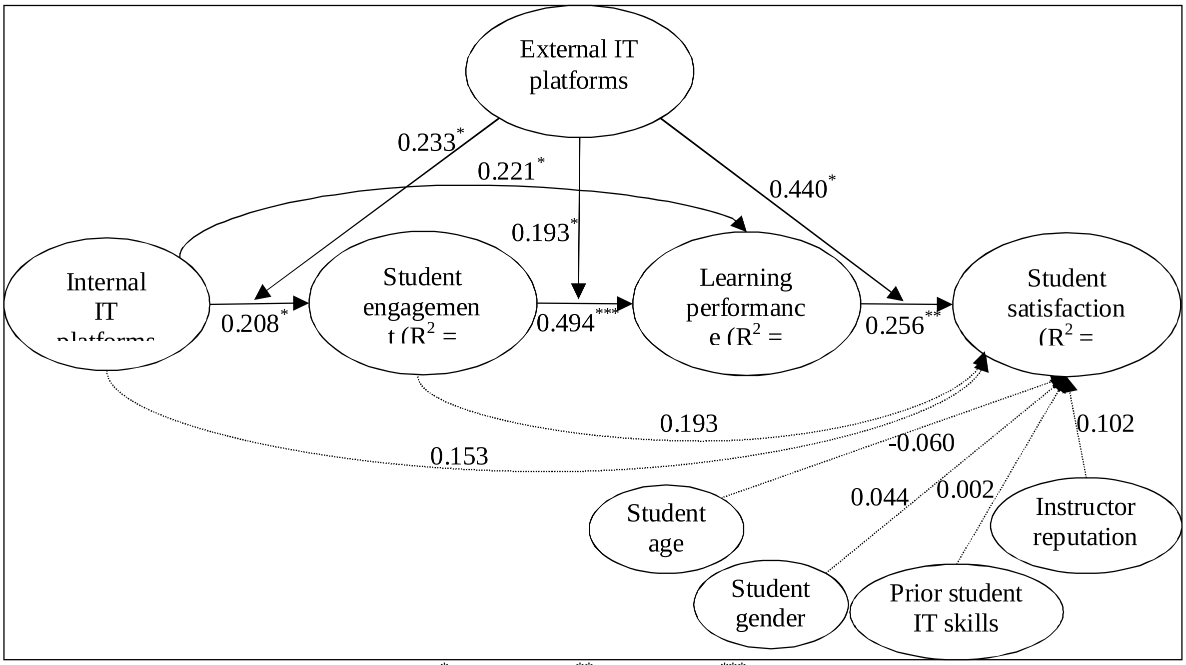

Figure 1. Test of hypotheses ($^{*}p < 0.050$, $^{**}p < 0.010$, $^{***}p < 0.001$, one-tailed test)

This study also examines the standardized root mean squared residual (SRMR), unweighted least squares (ULS) discrepancy (d_{ULS}), and geodesic discrepancy (d_G) at first- and second-order level to evaluate the goodness of structural model fit (Henseler et al., 2014; Henseler and Dijkstra, 2015). These goodness of fit measures evaluate the discrepancy between the empirical correlation matrix and the model-implied correlation matrix (Benitez and Ray, 2012; Henseler, 2015). The lower they are, the better the fit of the research model (Henseler and Dijkstra, 2015). Both measurement models, at the first and second-order steps, should not be rejected based on the alpha level of 0.05 as all discrepancies are below the 95%-quantile of the bootstrap discrepancies (Table 2). Overall, the analysis suggests that there is good structural fit between the model and data at first- and second-order level (Henseler and Dijkstra, 2015).

Mediation analysis

A mediation analysis is conducted to examine the mediation effects involved in the proposed model. We add to the base model a link between: (1) internal IT platforms and learning performance, (2) internal IT platforms and student satisfaction, and (3) student engagement and student satisfaction. All the indirect effects are significant at 0.05 level, which reinforces the results obtained in the test of hypotheses. The effect of internal IT platforms on learning performance through student engagement is significant. The effect of internal IT platforms on student satisfaction through student engagement and learning performance is significant. The effect of student engagement on student satisfaction through learning performance is also significant. All the indirect effects are significant at a 0.050 level (Zhao et al., 2010). Table 3 provides details of the mediation analysis.

Table 1. Effect size analysis

Relationship	f^2 value	Effect size
Hypothesized relationship	**f^2 value**	**Effect size**
Internal IT platforms → Student engagement (H1)	0.037	Weak
Student engagement → Learning performance (H2)	0.447	Large
Learning performance → Student satisfaction (H3)	0.144	Medium
Internal IT platforms * External IT platforms → Student engagement (H4)	0.041	Weak
Student engagement * External IT platforms → Learning performance (H5)	0.047	Weak
Learning performance * External IT platforms → Student satisfaction (H6)	0.475	Large
Control variables	**f^2 value**	**Effect size**
Student age → Student satisfaction	0.016	Weak
Student gender → Student satisfaction	0.010	Very weak
Prior student IT skills → Student satisfaction	0.000	Zero
Instructor reputation → Student satisfaction	0.054	Weak-medium

Table 2. Structural model fit evaluation

Discrepancy	First step			Second step		
	Value	HI95	Conclusion	Value	HI95	Conclusion
SRMR	0.075	0.088	Supported	0.082	0.154	Supported
d_{ULS}	3.322	4.631	Supported	3.723	13.261	Supported
d_G	1.812	3.406	Supported	2.053	5.239	Supported

Table 3. Mediation analysis

Relationship	Direct effect	Indirect effect
Internal IT platforms→ Learning performance	0.221^{*}	0.103^{*}
Internal IT platforms→ Student satisfaction	0.153	0.123^{*}
Student engagement→ Student satisfaction	0.193	0.126^{**}

Test of robustness

We check for the robustness of the proposed model in two ways. First, we triangulate the measurement model by measuring learning performance with secondary data on the grade obtained by the student in the course. We correlate learning performance measured with survey data and learning performance measured with secondary data and they are correlated (0.403^{***}), which gives additional credibility to our perceptual measure on learning performance (Benitez and Ray, 2012). This analysis suggests that measurement specifications are not a concern in our empirical analysis.

Second, we check the robustness of the structural model. Since it may be discussed that a greater course satisfaction may be positively related with learning performance, we consider an alternative model in which student satisfaction influences learning performance, keeping every other relationship the same (Figure A1 in the appendix). The empirical analysis yields confusing results comparing to our proposed model (Figure 1). In the proposed model, the direct effect of internal IT platforms on learning performance is significant while the direct relationships between internal IT platforms and student engagement on satisfaction are not significant. In the alternative model the opposite happens: (1) the direct relationship of internal IT platforms on learning performance is not significant, (2) while the direct effects between internal IT platforms and student engagement on satisfaction are significant. In the alternative model the moderating effect of external IT platforms on the link between student satisfaction and learning performance is not significant, and the model have greater discrepancy values (SRMR, d_{ULS}, and d_G) (Table A2 in the appendix) as compared with the proposed model (Table 2), which indicates a poorer goodness of fit.

Discussion and conclusions

This research examines the impact of internal and external IT platforms on Management education using the case method. We theorized that internal IT platforms may enable instructors to engage students to increase learning performance, which in turn leads to a greater student satisfaction, and that external IT platforms (i.e., social media for teaching activities) may amplify the relationships between internal IT platforms, student engagement, learning performance, and student satisfaction. The empirical analysis gives support to our theory.

We find that internal IT platforms influence student satisfaction through student engagement and learning performance, at the time external IT platforms reinforce these effects. First, the usage of internal IT platforms as a complement of classroom setting enables a greater student engagement because the instructor's efforts in providing structured teaching materials, updating the course content information or quickly solving doubts through information technologies such as Moodle-based learning platform or e-mail. Second, as long as the student feels a sense of involvement with the learning process, its knowledge perception improves due to the collaborative environment created in class. Engaged students are more motivated to collaborate and create new discussion experiences at the time they feel a sense of control over the learning process. Third, the learning outcomes obtained effectively affect the student satisfaction with the instructor, course, and teaching method. Student satisfaction is thus explained by the extent students assimilate knowledge and learn to make managerial decisions to solve business problems. Finally, external IT platforms perform an amplifier role on these relationships because the interactivity and conception of group, which make easier the student involvement in the process of learning, their effective knowledge acquisition and satisfaction with the course. Our results are somewhat against Piccoli et al. (2000), who found that students employing virtual networks are less satisfied with the learning experience. Differences can be explained to the fact that Piccoli et al. (2000) did not explore the effects of external social media platforms in their study. Social interactivity, agility, enjoyment, and conception of group revealed in external IT platforms (e.g., Facebook, Twitter) can strongly explain the student satisfaction.

Our research has the following contributions to research on IS and Management Learning. While prior research has focused in comparing the outcomes of traditional and online learning (e.g., Redpath, 2012), we explore the role of internal and external IT platforms in blended learning Management courses using the case method. The first contribution of this study is the conceptualization of IT platforms and its classification in internal and external IT platforms as an enabling (i.e., internal IT platform) and complementary resource (external IT platforms) in Management education using the case method. Second, this research theorizes, theoretically explains, and empirically demonstrates how internal IT platforms increase student satisfaction by enabling student engagement and improving learning performance. The third incremental contribution of this paper is to investigate and theorize the role of social media in Management learning using the case method. Finally, we consider learning performance as exogenous of student satisfaction. Our study is the first in exploring empirically the direct relationship between learning performance and student satisfaction. While some studies consider interactivity (among students, and among students and the instructor) and social capital as antecedents of perceived learning and student satisfaction (Arbaugh and Benbunan, 2007; Lu et al., 2013), surprisingly, any prior study has explored the relationship between learning performance and student satisfaction.

This study also provides key teaching lessons to Management instructors. We give some answers to the question of complementary or overlapping using internal and external IT platforms in a Management course. A case method-based course of Management can be improved with the usage of internal and external IT platforms. The usage of internal IT platforms engages the student to improve its learning performance and student satisfaction. Once the internal IT platforms are being used, it is critical to carefully decide and select whether and what social media may be used. If this is performed effectively, social media can positively reinforce the IT-based improvement of the teaching activities of the course. Based on our empirical results, we can tell instructors that internal (e.g., email, Moodle-based learning platforms, laptop usage, instructor's web site), and external (e.g., Facebook, Twitter, Pinterest, LinkedIn, Google +) IT platforms dance together in the execution of the learning activity, hence improving the student learning output (i.e., learning performance and student satisfaction). In conclusion, the combination of traditional classroom setting with IT platforms improves the interactive learning process in Management education. Blended learning based on a combination of traditional information technologies (internal IT platforms) with more interactive and user friendly information technologies (external IT platforms) enable a better learning performance that ends up with a greater satisfaction of the students.

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Appendix

Table A1. Measurement model evaluation at first- and second-order level

Construct/indicator	VIF	Weight	Loading
Internal IT platforms			
I have used the laptop in the course (e.g., to ask for a meeting with the instructor, solve doubts)	1.183	0.436^{*}	0.650^{***}
I have used the email in the course	1.016	0.127	0.157
I have used the internal teaching platforms of the School in the course	1.030	0.726^{**}	0.814^{**}
I have used the instructor's web site in the course	1.163	0.249	0.425^{*}
Student engagement			
I have been motivated to participate and collaborate in the course	2.899	0.698	0.978^{***}
I have been involved to participate and collaborate in the course	3.757	0.256^{**}	0.902^{***}
I have been emotionally committed to contribute in the course	2.341	0.112	0.765^{***}
Learning performance			
I have learned to make managerial decisions in the course	2.968	0.152^{***}	0.774^{***}
I have learned to make human resource decisions in the course	2.795	0.179^{***}	0.808^{***}
I have learned to think and behave like a senior manager in the course	1.723	0.135^{***}	0.644^{***}
I have understood key managerial concepts in the course	1.496	0.179^{***}	0.647^{***}
I have learned to identify key topics for a real business situation in the course	1.712	0.164^{***}	0.682^{***}
I have developed the ability to communicate clearly on the topics of the course	1.830	0.166^{***}	0.693^{***}
I have learned to solve firm/managerial problems in the course	1.960	0.124^{***}	0.663^{***}
I have learned to think critically in the course	2.015	0.145^{***}	0.696^{***}
I have learned to answer the key questions on each case in the course	1.880	0.181^{***}	0.692^{***}
Student satisfaction			
Instructor satisfaction	2.533	0.707^{***}	0.953^{***}
The course organization has been really good	1.724	0.150	0.697^{***}
The instructor has made his work really good	2.805	0.557^{**}	0.948^{***}
The course climate has been really good	2.648	0.113	0.829^{***}
The instructor has strived in responding doubts and solving questions	2.830	$0.306^{\dagger}$	0.893^{***}
Course satisfaction	2.979	0.055	0.833^{***}
I am very satisfied with the course	2.525	0.175	0.753^{***}
The course has met/exceeded my expectations	2.388	$0.344^{\dagger}$	0.760^{***}
The quality of the course has been really good	1.298	0.674^{**}	0.900^{***}
Teaching method satisfaction	1.807	0.352^{*}	0.797^{***}
The teaching method enables me to know the degree of the managerial skills that I have developed in the course	1.948	0.248^{*}	0.726^{***}
The teaching method enables me to know the degree of knowledge that I have acquired in the course	2.484	0.038	0.735^{***}
The teaching method has helped me to learn from my mistakes	2.020	0.179	0.722^{***}
The teaching method has persuaded me to strive in the course	2.870	$0.286^{\dagger}$	0.886^{***}
The teaching method has enabled me to collaborate and communicate with other students	1.943	0.188	0.778^{***}
The teaching method has motivated me to study and work very hard	1.806	0.328^{*}	0.797^{***}

External IT platforms			
I have used Facebook in the course	1.149	0.039	0.331†
I have used Twitter in the course (e.g., to participate in the virtual case discussion)	1.105	0.209	0.444†
I have used Pinterest in the course	2.165	0.556†	0.926*
I have used LinkedIn in the course	1.765	0.285*	0.736**
I have used Google + in the course	1.262	0.290	0.589†
Prior student IT skills			
My level of prior skills using internal IT platforms (e.g., internal teaching platforms of the School, laptop) was good	1.160	0.694*	0.882**
My level of prior skills using external IT platforms (e.g., Twitter, Facebook, LinkedIn) was good	1.160	0.507†	0.765**
Instructor reputation			
The reputation of the instructor in terms of learning quality was good	3.579	0.281	0.918**
The reputation of the instructor in terms of the student's learning performance was good	3.579	0.751†	0.989**

Table A2. Second alternative model fit evaluation

Discrepancy	**Structural model**		
	Value	HI_{95}	Conclusion
SRMR	0.083	0.148	Supported
d_{ULS}	3.831	12.229	Supported
d_G	2.070	5.368	Supported

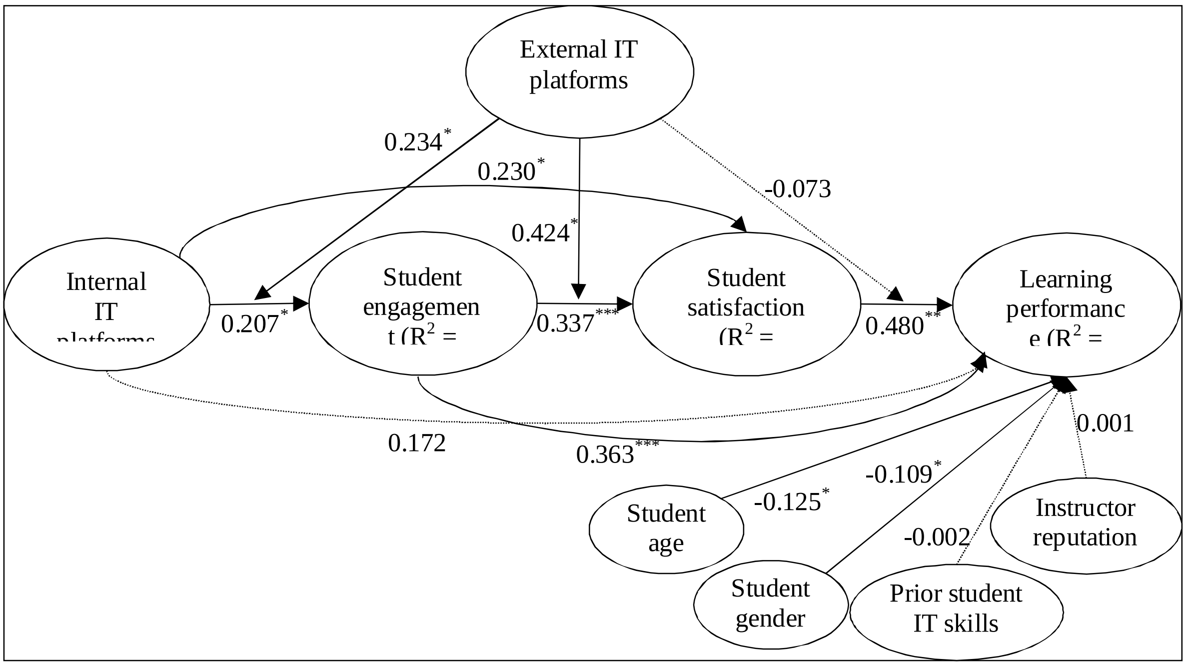

Figure A1. Second alternative model: Student satisfaction influences learning performance

OPEN INNOVATION AND QUALITY MANAGEMENT: THE MODERATING ROLE OF INTERORGANIZATIONAL IT INFRASTRUCTURE AND COMPLEMENTARY LEARNING STYLES

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Abstract

The relationship between open innovation and performance can be influenced by factors such as organizational context. In our study we analyze quality improvement commitment as an organizational context. Specifically, we propose that, to contribute to open innovation performance, an organization's commitment to quality improvement must rely on the combination of its own resources and capabilities and those that compose its supply network. In particular, we propose and verify based on a sample of 270 firms, the need to establish an interorganizational IT infrastructure and achieve complementarity of learning styles with that of its supply network.
Keywords: Open innovation; Interorganizational IT infrastructure; Organizational learning styles.

Introduction

Organizations coexist with complex, dynamic environments and have in the past decade faced factors such as high cost of technological development, reduced product life cycle and increase in the mobility of qualified workers (Laursen and Salter, 2006). This business reality has made the traditional concept of innovation obsolete. Therefore, organizations are increasingly conscious of the need to open the boundaries of their R&D departments to the exterior and orient themselves to open innovation. Open innovation is "a process of distributed innovation based on intentionally managed knowledge flows beyond the boundaries of an organization (Chesbrough and Bogers, 2014). The relation between openness and innovative performance has been considered a key aspect of analysis in studies of innovation (Knudsen and Mortensen, 2011; Love et al., 2014a; Mazzola et al., 2012; Parida et al., 2012), but no consensus exists in the literature, as studies reach disparate conclusions.

Our study seeks to contribute to the literature that analyzes the relationship between open innovation and innovative performance, focusing attention on a specific innovation source, suppliers. The importance of suppliers as a source of successful ideas and innovation has been widely recognized in the literature that analyzes the sources of innovation generically in an organization operating under open innovation (Laursen and Salter, 2006; Un et al., 2010). The study by Enkel et al. (2009) indicates that 69% of knowledge sources come from suppliers. The literature has also shown the benefits on the level of innovation of using the organization's suppliers' orientation to innovation, taking the supply network as the unit of analysis (Bellamy et al., 2014). Narasimhan and Narayanan (2013, p.28) provide a definition of supply network that focuses on an organization's upstream suppliers and includes the paradigm of open innovation. Their study thus defines the supply network as "the possible network of upstream suppliers in the firm's value system directly or indirectly". Following this definition, we understand open innovativeness to be the degree to which an organization puts this new paradigm into practice, specifically the extent to which it develops coupled processes with the members of its supply network. We thereby address the need to examine the specific innovation practice to understand the effect of this new paradigm on innovative performance.

The relationship between openness and innovation depends not only on the specific practice of open innovation considered here, but also on the context of the organization committed to innovation (Di Benedetto, 2010; Huizingh, 2011; Lichtenthaler, 2011). We thus find studies that demonstrate the influence of the organization's strategic orientation (Cheng and Huizingh, 2014) or fit with the business model (Saebi and Foss, 2015) as organizational aspects that moderate these relationships. Along these lines, our study responds to the need to deepen the analysis of the relationship between openness and innovation as a function of the organizational context. Specifically, we analyze the influence of commitment to improving quality in the organization (concretely, through adoption of a quality management system with ISO 9000 certification) on obtaining benefits from an organization's orientation to open innovation using its supply network.

Controversy exists in the literature concerning the effect of ISO standards on innovation. Detractors point to excess bureaucracy as the main disadvantage, whereas defenders indicate the standards' importance in permitting cultural change and permeability of the organization's boundaries. This issue is especially important for an organization committed to open innovativeness and quality. The lack of consensus in the literature that studies the relationship between innovation and quality indicates the need to take other factors into account in explaining this relationship, however. This need is demonstrated in the study by Pekovic and Galia (2009), which proposes that an organization must be supported by its resources and capabilities if its commitment to improving quality is to translate into better innovative performance. This is why we examine the fit between an organization's resources and capabilities and its supply network. More specifically, we will analyze the moderating character of the complementarity between learning styles and compatibility of an organization's information technologies with those of its supply network in the relationship between openness and innovative performance.

Complementarity between learning styles can be linked to a high level of exploration and exploitation in the organization committed to improving quality and open innovation, an aspect essential to maintaining competitive advantage over time (Rothaermel and Alexandre, 2009; Wei et al., 2014). Information technologies facilitate open innovation activities and must thus be taken into account in studying this new paradigm, as is shown by the recent study by Cui et al. (2015). Further, since information technologies have been shown to constitute an essential factor for knowledge transfer and improvement in performance for organizations that pursue quality (Sánchez Rodríguez and Martínez Lorente, 2011), their compatibility can be essential for organizations that adopt open innovation and have implemented ISO 9000 norms.

The general goal of our study is to clarify the relationship between an organization's orientation to open innovation, understood in relation to the development of coupled processes with its supply network, and innovative performance. This goal takes concrete form in two individual objectives. The first is to study the relationship between an organization's orientation to open innovation and innovative performance based on whether or not the organization analyzed has implemented ISO 9000 standards. The second is to analyze the moderating role of fit between the organization's resources and capabilities and its supply network in an ISO 9000 context, specifically, the complementarity between learning styles and the establishment of an interorganizational IT infrastructure.

To fulfill these objectives, the study is structured as follows. The first section provides a review of the most relevant literature, followed by our proposal of a theoretical model and hypotheses. Next, we present the methodology, including data collection, measurement instruments, and control variables. The empirical results are then presented, followed by a discussion of findings. Finally, we discuss the theoretical and managerial implications, research limitations, and future lines of research.

Theory and hypotheses

Open innovation and innovative performance

The benefits associated with adoption of open innovation in an organization are the subject of debate in the literature. Some studies show the benefits of adopting open innovation in terms of profitability and growth (Chiang and Hung, 2010; Lichtenthaler, 2009), R&D performance (Chiesa et al., 2008), customer satisfaction (Chesbrough, 2010; Cheng and Huizingh, 2014; Wagner, 2010), degree of product innovation (Cheng and Huizingh, 2014; Ebersberger et al., 2012; Gassmann, 2006; Grimpe and Sofka, 2009; Laursen and Salter, 2006), commercial success of new products (Barge-Gil, 2013; Cheng and Huizingh, 2014; Ebersberger et al., 2012; Love et al., 2014b) and the results of exploratory and exploitative innovation (Faems et al., 2005).

If we examine the types of innovation, we find that the positive effect of both product and process innovation has been confirmed (Huang and Rice, 2012). As to the degree of radicality of innovation resulting from adoption of open innovation, the study by Parida et al. (2012) argues theoretically the possibility of obtaining both incremental and radical innovations, although this result depends on the practice of open innovation considered. Chiang and Hung (2010) argue that the way external knowledge is accessed determines organizational learning and thus the radicality of the innovation, asserting that open search depth leads to incremental innovations, in contrast to open search breadth, contradicting the conclusions of Laursen and Salter (2006). The positive effects of co-development or joint research between partners are shown generally on the theoretical level by Chesbrough and Schwartz (2007), and the necessity of fit between the partners’ business models is also stressed. Collaboration with suppliers, the topic of our study, has been shown to influence innovative performance significantly (Mazzola et al., 2012; Un et al., 2010), in addition to influencing achievement of radical innovation (Köhler et al., 2012; Pullen et al., 2012).

Among the drawbacks, another branch of the literature analyzes the possible disadvantages of excessive openness in the organization, which include incurring excessive costs in exploration of knowledge (Katila and Ahuja, 2002; Laursen and Salter, 2006) or the drawback of certain organizational attitudes toward open innovation (Lichtenthaler and Lichtenthaler, 2010). Other studies, such as those by Spithoven et al. (2011) and Suh and Kim (2012) show the absence of an effect on innovative performance, or a substitution effect between internal and external openness, as in the case of Knudsen and Mortensen (2011), who disagree with the study by Dahlander and Gann (2010).

The clear absence of consensus in the literature has prompted calls to examine the different organizational contexts that can explain this relationship, as it is more complex than it seems (Di Benedetto, 2010; Huizingh, 2011; Lichtenthaler, 2011). Our study responds to these calls by analyzing the influence of ISO certification on the relationship between orientation to open innovation and innovative performance. As this factor has not been taken into account to date, our study both contributes to clarifying the relationship between open innovation and innovative performance and opens a line of future research on the influence of commitment to quality and the adoption of open innovation.

The relationship between quality management and open innovation. ISO 9000 as an organizational context

The family of ISO 9000 standards is an international standard of quality management introduced in 1987 (Prajogo et al., 2012) but that still continues to generate debate concerning its effect on organizational performance. We have seen that one branch of the literature proclaims its positive effects by promoting continuous improvement in the certified organization, thereby constituting a precedent to total quality management. Detractors argue, however, that implementation brings not commitment to quality but more bureaucratization and less flexibility and innovation (Kuo et al., 2009).

As shown by Huo et al. (2014) and Terziovski and Guerrero (2014), the literature has hardly treated the relationship between ISO standards and innovation (as compared to total quality management). Our study seeks to contribute to the literature by considering the effect of ISO certification and its philosophy on achieving new coupled developed products, services, and/or processes that result in benefits for both the organization and its suppliers.

First, opening an organization requires cultural change that will guarantee permeability of its boundaries and two-way knowledge transfer. We can think that this change can be facilitated if the organizations have ISO certification, since several studies have shown that, independently of degree of implementation, quality programs based on these standards facilitate organizational change (López-Mielgo et al., 2009). An organization that follows the standards imposed by these norms achieves customer satisfaction while reducing inefficiencies, a result achieved through management by processes, both internal and external (Naveh and Marcus, 2005).

Although a certified organization can be oriented to open innovation, we find studies that lead us to think that this commitment to quality improvement can shrink the benefits derived from adopting the new paradigm in the organization. A recent study by Huo et al. (2014) demonstrates empirically that ISO 9000 standards do not promote innovation, since they focus their attention simply on achieving the "conformity" established in their standards.

Similarly, studies like those by Corbett et al. (2005), Naveh and Marcus (2005), Prajogo and Sohal (2004) and Terziovski and Guerrero (2014) demonstrate the inconsistency between the goals the standard pursues and those required for innovation. These authors point to the fact that the ISO 9000 quality management system pursues reduction of variability in processes and emphasizes high standardization and attention to detail, which can lead to greater rigidity (Prajogo and Sohal, 2004) and inhibit innovation. Along these lines, the study by Gotzamani and Tsiotras (2002) demonstrates that ISO 9000 standards foster bureaucracy instead of innovation.

The study by Benner and Tushman (2003) indicates the suitability of these standards in stable environments, a finding that conflicts with the philosophy under which the new paradigm of open innovation operates. Further, another study by Benner and Tushman (2002) relates these standards to exploitation of knowledge that already exists in the organization and the search for a more local-level, philosophy able to induce lower porosity of the organization to the outside environment. The arguments advanced by opponents of the relationship between innovation and quality improvement under ISO 9000 standards are summarized in the paradox highlighted by Swann (2010): the most innovative organizations find their innovative activities limited by the regulation present in these standards. The study by Terziovski and Guerrero (2014) also demonstrates this paradox, stressing that the quality improvement this management system pursues emphasizes avoiding failure, but failure goes hand in hand with experimentation required to innovate. Based on the foregoing, we propose to verify the following hypothesis:

Hypothesis 1 (H1). ISO 9000 standards have a negative and significant influence on the relationship between open innovativeness and open innovation performance.

The moderating role of complementary learning styles and interorganizational IT infrastructure on the relationship between quality management and open innovation

The debate in the literature on the relation between innovation and commitment to quality improvement represented by ISO 9000 standards leads us to think that this relationship is more complex than it appears. Following the study by Pekovic and Galia (2009), we believe that, for commitment to quality improvement to influence innovation performance, this commitment must be integrated with the organization's resources and capabilities. Given that our study focuses on orientation to open innovation, we propose that fit between the organization's resources and capabilities and its sources of innovation permit the organization to obtain better innovation performance when it has a dual commitment: quality improvement and open innovation.

Specifically, we study the effect of complementarity in learning styles and establishment of an interorganizational infrastructure of information technologies (compatibility of technologies) between an organization and the suppliers with which it practices open innovation. Complementarity between learning styles permits ambidexterity in the organization oriented to innovating openly, and it can lead to obtaining benefits from this orientation. Further, compatibility of information technologies ensures flow of knowledge beyond the boundaries of an organization, which is also key to obtaining benefits from orientation to open innovation.

Complementary learning styles

Organizational learning takes place when the organization “makes use of its prior experience and assimilates external knowledge” (Dong and Yang, 2015, p.112). Following the seminal study by March (1991), an organization’s learning style can be classified into two types, exploratory and exploitative learning. Exploitation involves “learning based on certainty,” whereas exploration is “learning based on probability” (Azadegan and Doley, 2010, p.490). March (1991, p.71) defines the term exploration as ‘‘search, variation, risk-taking, experimentation, play, flexibility, discovery, and innovation’’ and exploitation as ‘‘refinement, choice, production, efficiency, selection, implementation, and execution.’’

These two learning styles pursue different ends, but neither by itself is a panacea, as both styles are necessary to the organization’s survival and the maintenance of a competitive advantage in terms of efficiency and creativity. This reasoning supports the benefits of coexistence of the two styles in the organization. The notion of ambidexterity has been interpreted extensively. One interpretation holds that ambidexterity is the coexistence of a high level of exploration and low level or exploitation, or vice versa (Atuahene-Gima and Murray, 2007; Benner and Tushman, 2003; Nerkar, 2003).

We must remember that, according to the literature, maintaining high levels of exploration and exploitation permits an organization to achieve better results (Rothaermel and Alexandre 2009; Wei et al., 2014). The commitment to open innovation of organizations that are also certified compels them, however, to a certain extent of exploratory behavior. Despite this, following the line of reasoning in Moreno-Luzon et al. (2014), we believe that the balance tips more toward exploitative than exploratory learning in these cases. Benner and Tushman (2003) attempt to determine the role of ISO in an organization’s exploratory or exploitative behavior, indicating that the founders of managing by processes pursue primarily incremental innovation, encouraging exploitative learning over explorative. Their study shows that managing by processes promotes continuous innovation and change but induces the use, first, of existing knowledge and capabilities in the organization, tipping the balance toward highly exploitative learning.

Our study proposes the possibility of compensating for lower levels of exploratory learning in an organization, if the organization is oriented to innovating openly with suppliers that complement its learning style, that is, that are more exploratory. We thus ask whether it is better, when pursuing innovation performance under the ISO 9000 standard, to have orientation to open innovation with suppliers who have a similar learning style or a complementary one.

Azadegan et al. (2008) suggest that maintaining relationships with suppliers with a learning style complementary to that of the organization enables overcoming of rigidities that could emerge if the organization and its supply network have the same style of learning. Thus, the organization that exploits excessively can obtain benefits from exploring, and vice versa, if it achieves complementarity with its supply network. The literature shows that complementarity between the learning styles of partner firms constitutes a source of knowledge from which radical innovations develop (Dussauge et al., 2000; Rothaermel and Boeker, 2008). Since learning is a capability of the organization, it can be strengthened by maintaining relationships with partners that strengthen it in the style in which it is weaker, as proposed by Rothaermel and Boeker (2008). Dussauge et al. (2000) show that complementarity between resources and capabilities of partners permits greater interorganizational learning and fewer exploitative results. Based on the foregoing, we seek to verify empirically the following hypothesis:

Hypothesis 2 (H2). Complementarity between learning styles of certified organizations and its supply network positively moderates the effect of open innovativeness on open innovation performance.

Interorganizational IT infrastructure

We understand interorganizational IT infrastructure as shared technology and technology services across organizations (Kim et al., 2012, p.41). Through it, an organization can make use of its IT resources (databases, software, etc.) to access other resources in other organizations that for example form part of its supply chain (Weill and Vitale, 2002). These resources include knowledge, which can also reduce the cost of accessing knowledge (Colombo and Mosconi, 1995). Among the benefits derived from interorganizational IT infrastructure is improvement in operating performance of the organization that possesses information technologies compatible with those of its supply chain (Malhotra et al., 2007; Obal and Lancioni, 2013).

It is thus especially interesting for our study to consider that information technologies can serve to support quality management activities (Delic et al., 2014) and improve their performance (Pérez et al., 2012). For this reason, information technologies have been seen as complementary in character and as facilitating knowledge creation in organizations committed to quality (Sánchez Rodríguez and Martínez Lorente, 2011).

The literature identifies interorganizational IT infrastructure as a factor that facilitates knowledge transfer between organizations, permitting joint activity and rapid exchange of information between them. Studies also show its positive effect on interorganizational collaboration (Richey et al., 2012) and coordination (White et al., 2005). Further research finds that interorganizational IT infrastructure permits greater performance in interorganizational relationships and exploitation of the synergies between their members (Im and Rai, 2014; White et al., 2005).

The literature on information systems shows that information technologies are a key tool for achieving learning and innovation in an organization (Dong and Yang, 2015). Their influence on the acquisition and assimilation of external knowledge has also been shown (Tippins and Sohi, 2003; in relation to the supply chain: Malhotra et al., 2007; Subramani, 2004), as well as their ability to promote information exchange and knowledge transfer (Frank et al., 2014; Kleis et al., 2012; Roberts and Grover, 2012). Information technologies also influence coordination of processes between organizations and benefit development of new products and services (Kleis et al., 2012; Roberts and Grover, 2012).

IT has been linked to cultural change to open the organization's boundaries (Dodgson et al., 2006; Kleis et al., 2012), stressing its ability to facilitate open innovation practices (Chesbrough, 2003; Obal and Lancioni, 2013; Westergren, 2011) and adoption of this new paradigm in generating ideas and their development and commercialization (Awazu et al., 2009; Xue et al., 2012). The study by Dong and Yang (2015) shows how information technology investment enables obtaining benefits from external oriented organizational learning processes, processes that define the open innovation paradigm. The study by Cui et al. (2015), in turn, proposes the positive effect of integrating information technologies into implementation of an organization's open innovation strategy, specifically in open search depth. This study suggests that integration of information technologies supports exchange of tacit knowledge with possible sources of innovation with which the organization maintains a closer relationship. It thus holds that information technologies contribute to generating social capital and reducing the possibility of suffering opportunistic behavior in organizations oriented to open innovation with a low number of partners. Based on the foregoing, we propose to verify the following hypothesis:

Hypothesis 3 (H3). Interorganizational IT infrastructure in certified organizations positively moderates the effect of open innovativeness on open innovation performance.

The joint consideration of these hypotheses produces the theoretical model in Figure 1.

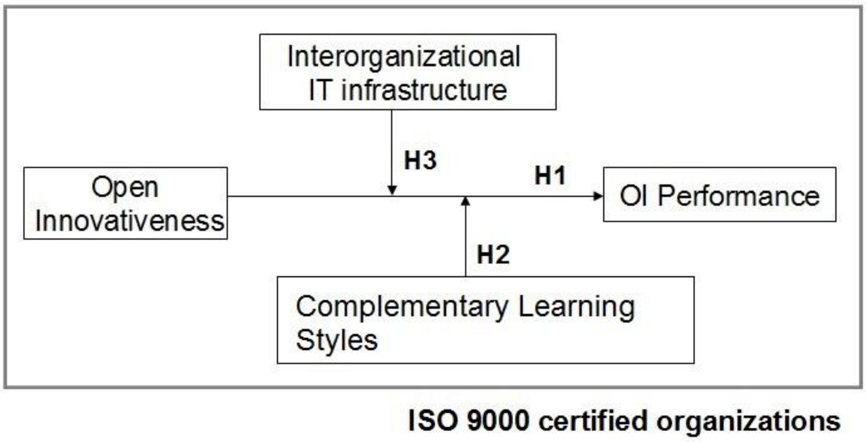

Figure 1. Theoretical model

RESEARCH METHODOLOGY

Sampling and data collection

To test the different hypotheses, we performed an empirical study of manufacturing and service firms. The SABI databases were used to obtain the study population. A sample of 2000 European firms was chosen at random. Initially, a pretest was used to determine the scale. The scale was carefully examined by selected practitioners and academicians in this area for translation, wording, structure, and content. The scale's content validity should be sufficient.

In all cases considered valid, the informants were logistics/purchasing executives. A CATI (computer-assisted telephone interviewing) survey method was used for the study.

We received 290 responses, for a response rate of 14.5%. Accounting for missing responses, we obtained a final sample of 270 usable responses, yielding a final response rate of 13.5%. Table 1 depicts the sample demographics. Possible bias due to non-responding firms was analyzed. Considering the late group of respondents as those most likely to be similar to non-respondents, we compared early and late groups of respondents to obtain information on non-response bias in the sample (Armstrong and Overton, 1977; Subramani, 2004). Early and late sub-samples were identified as 169 and 101 respondents, respectively. The results of comparing the two groups indicate no systematic non-response bias in the survey data (p=.05).

Table 1. Demographic

Characteristics	Frequency	Percent
Industry type		
High-tech Manufacturing	79	29.26%
Traditional Manufacturing	100	37.04%
Services	91	33.7%

Annual revenue		
<1000M	0	0
1000-10,000M	83	30.74%
10,000-100,000M	158	58.52%
>100,000M	29	10.74%
Number of employees		
0-49	13	4.82%
50-250	202	74.81%
>250	55	20.37%
Number of suppliers		
<100	226	83.7%
100-300	38	14.08%
>300	6	2.22%

Measures

Given the absence of literature on measuring an organization's orientation to open innovation put into practice with its supply network, we have developed this measurement. We based our work on the operationalization of open innovation by the European Foundation for Quality Management (EFQM, 2013) and the theoretical study by Gassmann and Enkel (2004). In our study, therefore, *open innovativeness* measures the extent to which firms are oriented to open innovation and specifically to develop coupled processes (outside-in and inside-out activities) with its supply network. This construct includes the degree to which an organization pursues development of management practices that permits it to develop coupled processes with its supply network, specifically, the extent to which generation of ideas and innovation are promoted to be performed by its supply network and to which clear goals and objectives for innovation are established together and perfected based on the results obtained.

Likewise, this construct includes the cultural fit the organization perceives itself to have with its supply network to embrace this paradigm, specifically, the extent to which both conceive innovation as going beyond technological changes to indicate new ways of satisfying the customer, as well as new ways of working that take maximum advantage of resources, competition, and alliances and foster a culture of entrepreneurs throughout the organization. Recent studies like that by Crema et al. (2014) and Cheng and Huizingh (2014) propose constructs consistent with the one we propose. We measured this construct using eight items (one item was deleted) for which the survey respondents were to indicate their degree of agreement or disagreement with the statements proposed on a Likert scale from 1 to 7 (1=totally disagree; 7=totally agree).

Complementarity between exploratory and exploitative learning styles was calculated following by Azadegan and Dooley (2010). We multiplied the difference between the score of the manufacturer and supply network (alignment) by its absolute value to obtain the degree to which the learning styles differed. Whereas exploratory learning shows predominant use of new ideas and procedures in an organization, causing its income from sales to proceed primarily from new products, exploitative learning assumes emphasis on improvement in efficiency, existing technologies, and continuous improvement of the organization's procedures, policies, and rules.

Interorganizational IT infrastructure was adapted using three items from the scale developed by Kim et al. (2012), which contains five items (two items were deleted). It indicates the compatibility between the IT resources of the members in the relationship, such as databases and operating systems, as well as the consistency of the data, their security, and the difficulty of interpreting them. A 7-point Likert-type scale (1 = ‘‘totally disagree’’ to 7 = ‘‘totally agree’’) was developed.

OI performance was developed for the objective of this study following the framework established in the study by Wincent et al. (2009). It is defined as the performance outcomes of open innovativeness in the last five years represented by the development of new products, services, or processes that benefit both through three items. Indicators were captured using a 7-point Likert scale, from “not at all increased” to “significantly increased”.

We examined the surveyed organization’s size and sector as control variables, as well as the number of suppliers with which it maintained open innovativeness. ISO certification was analyzed through a categorical variable. Consistent with research convention, we used logarithmic transformations for employees and number of suppliers.

EMPIRICAL ANALYSIS AND RESULTS

Construct validity

We assessed validity with confirmatory factor analysis for the scales. The results of the confirmatory analysis show that all indicators fulfill the three requirements: all factor loadings are significant ($t>1.96$; $p<0.05$) and greater than 0.5 and the value for individual reliability is above 50%.

Following Fornell & Larcker (1981), we used the average variance extracted to evaluate convergent validity. The AVEs for OI (0.62), Buyer’s exploratory learning (0.55), SN´s Exploratory Learning (0.55), Buyer’s Exploitative Learning (0.71), SN’s Exploitative Learning (0.67), Interorganizational IT infrastructure (0.67), and OI performance (0.66) exceeded the 0.5 criterion. Composite reliability exceeded the 0.7 criterion.

Discriminant validity is assumed to exist if the squared average variance extracted for each construct exceeds their shared variance. This was found in all combinations of paired constructs, providing evidence of discriminant validity for all scales. Table 2 shows the descriptive statistics, correlations among constructs and squared average variance extracted for each construct. Table 3 shows descriptive statistics and correlation matrices for the ISO and NON-ISO complementary learning models.

Table 2. Mean, standard deviation, correlations, and square root of AVE (complete model)

	1	2	3	4	5	6	7	8	9	10
1. OI	**0.78**									
2. Buyer´s EX L	0.517*	**0.74**								
3. SN´s EX L	0.456*	0.658*	**0.75**							
4. Buyer´s EXP L	0.184*	0.259*	0.331*	**0.84**						
5. SN’s EXP L	0.458*	0.532*	0.581*	0.434*	**0.82**					
6. IT	0.295*	0.395*	0.412*	0.213*	0.409*	**0.82**				
7. OI Performance	0.422*	0.409*	0.406*	0.157*	0.365*	0.306*	**0.81**			
8. Sector	0.001	0.053	0.053	-0.043	-0.103	-0.026	-0.027	1		
9. Employees (n)	-0.068	-0.041	-0.034	0.023	-0.073	0.075	0.005	0.025	1	

10. Suppliers (n)	0.049	0.022	-0.057	0.007	0.02	0.070	0.075	-0.687*	0.092	1
Mean	4.64	5.01	4.3	4.77	4.94	4.77	4.59	0.66	4.94	3.02
StDev	1.28	1.1	1.01	1.19	0.95	1.52	1.19	0.47	0.83	1.35
Mean Non-ISO	4.7	5.11	4.45	4.94	5.12	4.9	4.44	0.49	5.07	3.26
St Dev Non-ISO	1.28	1.12	0.83	1.15	0.89	1.54	1.19	0.5	0.99	1.5
Mean ISO	4.61	4.97	4.24	4.7	4.86	4.72	4.64	0.73	4.9	2.93
St Dev ISO	1.28	1.1	1.07	1.2	0.97	1.51	1.19	0.45	0.76	1.27

*p<0.01. Note: OI=Open Innovativeness; EX L=Exploratory Learning; EXP L=Exploitative Learning; IT=Interorganizational IT Infrastructure; SN= Supply Network

Table 3. Descriptive statistics and correlation matrices for the ISO and NON-ISO complementary learning models.

	Means ISO Non ISO	Sds ISO Non ISO	1	2	3	4	5	6	7
1. OI	4.61 4.44	1.29 1.19	-	0.013	0.064	0.556 ***	-0.031	-0.052	0.143
2. L FIT	-2.56 - 2.17	6.79 4.95	- 0.231 ***	-	0.177 *	-0.125	-0.12	0.069	0.124
3. IT	4.72 4.90	1.51 1.54	0.384 ***	- 0.108 *	-	0.309 **	-0.025	0.191 **	0.16*
4.OI Performance	4.64 4.44	1.19 1.19	0.376 ***	- 0.122 **	0.312 ***	-	-0.005	0.102	0.155*
5. Sector	0.73 0.49	0.45 0.50	0.025	0.077	-0.01	-0.063	-	-0.063	- 0.764* **
6. Employees	4.89 5.07	0.76 0.99	-0.081	0.114 *	0.011	-0.032	0.109 *	-	0.144
7. Suppliers	2.93 3.26	1.27 1.50	0.002	-0.083	0.021	0.053	- 0.644 ***	0.047	-

Note: First Mean and first SD scores are for ISO organizations. Lower Diagonal correlations are for ISO organizations. N= 195; Upper diagonal correlations are for NON-ISO organizations. N= 75; ***p<0,001; **p<0,05; *p<0,1; OI=Open Innovativeness; L FIT= Contrasting Learning Styles; IT=Interorganizational IT Infrastructure.

Hypothesis testing

To contrast the hypotheses, we used hierarchical regression analysis. Given the prior formulation of the hypotheses, contrasting them requires dividing the sample into two groups based on ISO 9000 standard certification. To avoid problems of multicollinearity, we centered the interaction terms relative to the mean before calculating their product. The tolerance value and the variance inflation factor (VIF) of the independent variables are within the accepted limited for rejecting the presence of multicollinearity.

We thus proposed two regression models, one for organizations that stated that they possessed the ISO 9000 certification (n=195) and the other for organizations that answered that they were not certified (n=75). The results of the hierarchical regression are presented in Table 4. Hypothesis 1 proposes that the relation between open innovativeness and OI performance will be statistically different among ISO and Non-ISO organizations. As can be seen in Model 3 of the first and second regression which incorporates the independent variable OI, this variable has a positive and significant effect in both cases, but ß is higher in the second case (ß (ISO)=0.275; ß (NON-ISO)=0.493). Introducing this variable shows a significant increase in the variance in both cases, meaning a change in R^2=0.07 in the first regression and a change in R^2=0.27 in the second.

We performed the Chow test to determine if there are significant differences among ISO certified and non-ISO certified firms. For a significant level of $p<0,1$, statistically difference exists among the effect on performance of open innovativeness in both groups.

Hypothesis 2 proposes that complementary learning styles moderate the relation between OI and OI performance in ISO 9000 organizations. If we examine the first regression, in Model 4, the product of OI and complementary learning styles shows a positive and significant sign, indicating that this interaction predicts OI performance significantly (ß=0.018; $p<0.01$). These results support the validity of H2. We plotted this interaction in Figure 2.

Hypothesis 3 holds that interorganizational IT infrastructure moderates the relation between OI and OI performance positively in ISO 9000 organizations. If we examine the first regression, in Model 4, the interaction between interorganizational IT infrastructure and OI correlates positively and significantly with OI performance (ß=0.103; $p<0.01$), supporting H3. We plotted this interaction in Figure 3.

Table 4. The effects of OI and its moderators on OI performance

	OI performance							
	ISO organizations n=195				Non-ISO organizations n=75			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
Constant	4.875c	3.694c	2.749c	2.797	2.823c	2.11c	0.105	0.131
Sector	-0.112	-0.112	-0.166	-0.093	0.623	0.44	0.202	0.185
Employees	-0.046	-0.035	-0.001	-0.041	0.082	0.037	0.094	0.102
Suppliers	0.025	0.013	0.066	0.001	0.274b	0.212	0.088	0.085
Learning FIT		-0.014	-0.005	-0.018		-0.046b	-0.046a	-0.047b
IT		0.239c	0.154c	0.18c		0.231c	0.215c	0.211c

OI			0.275c	0.256c			0.493c	0.486c
OI x L FIT				0.018c				0.005
OI x IT				0.103c				0.025
R^2	0.005	0.109	0.18	0.223	0.059	0.16	0.43	0.432
Adjusted R^2	-0.011	0.085	0.154	0.19	0.019	0.099	0.38	0.363
F	0.32	4.613c	6.871c	6.692c	1.487	2.625b	8.559c	6.275c
Change in R^2	0.005	0.104c	0.071c	0.044c	0.059	0.101	0.27	0.002
F	0.32	11.001c	16.295c	5.227c	1.487	4.135b	32.279c	0.101c

Note: The present coefficients are unstandardized regression results. a Significant at the 0.05 level; b Significant at the 0.1 level; c Significant at the 0.01 level. OI=Open Innovativeness; L FIT= Contrasting Learning Styles; IT=Interorganizational IT Infrastructure.

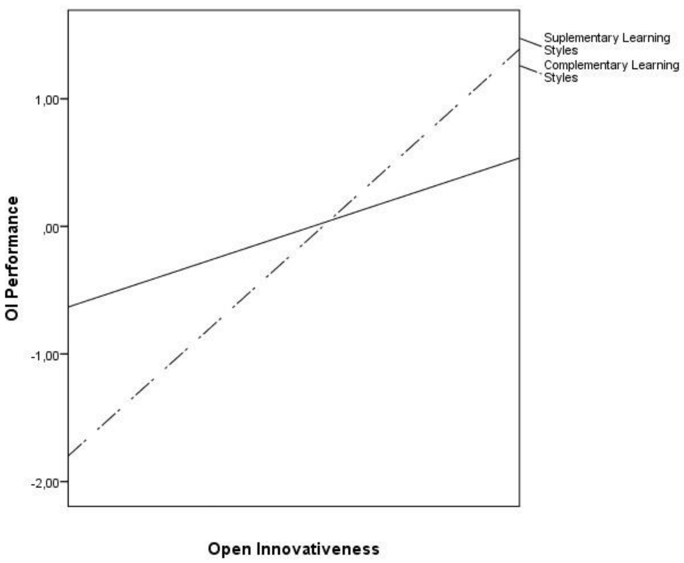

Figure 2. Moderation of open innovation-open innovation performance relationship by learning styles in ISO 9000 organizations.

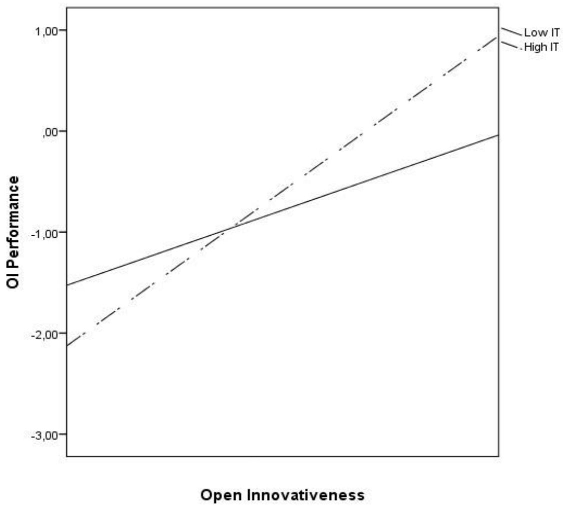

Figure 3. Moderation of open innovation-open innovation performance by interorganizational IT infrastructure in ISO 9000 organizations.

To complete the contrast of the hypotheses on moderation, we confirmed the presence of a significant moderating effect and then analyzed the sign and significance of the slope of the relation between OI and the dependent variable. Our procedure follows that proposed by Jaccard et al. (1990), based on the values taken by the moderating variable. We then performed an additional analysis, in which we evaluated the effect of the independent variable on the dependent variable, while distinguishing between different levels of the moderating variable. Analysis of the interaction term shows that OI is positively related to innovative performance under the condition of highly complementary learning styles and interorganizational IT infrastructure, as can be seen in Table 5. Because this effect is not significant when we establish the condition of low complementarity of learning styles and interorganizational IT infrastructure, we confirm that the multiplicative term is significant in the multiple regression analysis, providing support for H2 and H3.

Table 5. Effects of OI on OI performance for different levels of complementary learning styles and interorganizational IT infrastructure (organizations with ISO 9000)

	Model 1 High L FIT n=143		Model 2 Low L FIT n=52		Model 1 High IT n=106		Model 2 Low IT n= 89	
Constant	4.984c	3.027c	4.141c	3.584b	4.571c	2.768c	5.207c	4.152c
Sector	-0.128	-0.186	-0.109	-0.135	0.019	0.087	-0.341	-0.416
Employees	-0.084	-0.033	0.206	0.2	-0.013	-0.029	-0.099	-0.026
Suppliers	0.048	0.017	-0.087	-0.072	0.128	0.094	-0.063	-0.073
OI		0.410c		0.111		0.395c		0.19b
R^2	0.011	0.207	0.016	0.027	0.014	0.175	0.016	0.056
Adjusted R^2	-0.011	0.184	-0.046	-0.056	-0.015	0.142	-0.018	0.011
F	0.505	9.018c	0.256	0.327	0.494	5.36c	0.706	0.297

Note: The present coefficients are unstandardized regression results. a Significant at the 0.05 level; b Significant at the 0.1 level; c Significant at the 0.01 level. L FIT=Contrasting Learning Styles. IT=Interorganizational IT Infrastructure.

DISCUSSION AND CONCLUSIONS

This study analyzes the relationship between an organization's orientation to open innovation, put into practice with its supply network, and the improvement in innovative performance for both. Despite the importance of the supplier for putting open innovation into practice, few studies analyze this factor, a gap recognized in the literature on this new paradigm as in need of analysis (Thomas, 2013). Our study thus contributes doubly to understanding the benefits obtained from orientation to open innovation with one's supply network, by taking into account whether the organization has implemented ISO 9000 standards or not. Our results attest to the relationship between open innovativeness and innovative performance are consistent with a branch of the literature that argues the benefits of adopting open innovation in an organization, benefits in product, process, or service innovation with differing degrees of radicality (Parida et al., 2012).

Our results show, however, that certified organizations obtain less benefit from orientation to open innovation than uncertified ones. We thus join the branch of the literature that argues to conceal the complexity of the relationship between innovation and quality, making it necessary to examine other factors that condition it, such as the resources available to the organization (Pekovic and Galia, 2009). Following the study by Terziovski and Guerrero (2014), we argue that this result is due to the fact that formalization of procedures connected to the series of ISO standards is more necessary in some organizations than in others. Thus, the effectiveness of an organization's orientation to open innovation involves less bureaucratization, attention to detail, and formalization of procedures. To be effective, this new paradigm requires greater flexibility and openness to change than this certification provides.

Thus, following Benner and Tushman (2002), we believe that quality and innovation are not mutually exclusive, but it is essential to recognize that a higher degree of radicality in the innovations of an organization that operates under this quality management system involves examining other resources, whether organizational or interorganizational. Our results show that open innovation is more effective in organizations that pursue quality when they achieve complementarity in learning with their suppliers. This result confirms the benefits of ambidexterity in organizations that adopt open innovation. Complementarity between learning styles permits the organization that achieves fit with its supply network to enjoy the benefits of high levels of exploration and exploitation.

Our results also show the importance of compatibility between the organization's information technologies and those of its suppliers to obtain greater performance from open innovation in certified organizations. These organizations usually pursue external integration of their organization, tending to make compatibility of information technologies vital. Our results show the greater importance of this factor in certified organizations than in uncertified ones. Among certified organizations, our results also show its greater importance than the moderating role of complementarity of learning styles. This result is consistent with Cheng et al. (2014), who show the importance of flexible technological infrastructure to achieving interorganizational innovative performance. In our case, this is a tool that permits constant flow of knowledge between the organization and its suppliers, a key issue for achieving benefits from orientation to open innovation, confirming the results of the recent study by Cui et al. (2015).

Theoretical implications

This study contributes to developing the literature that analyzes the effects of adopting open innovation in an organization by examining its organizational context. The context used, commitment to quality by implementing ISO 9000 standards, permits us to extend the literature that analyzes quality and innovation and opens a new line of research, since no studies to date link open innovation and quality. Given the minimal literature on this topic (Wiengarten et al., 2013), the influence of ISO 9000 standards on innovative performance is a field in need of study, one that offers, among other advantages, the uniformity typical of standards and that permits comparison of organizations with each other, unlike total quality management.

Likewise, analyzing an organization's orientation to open innovation relative to a specific partner responds to the need recognized in the literature to study this relationship in detail (Obal and Lancioni, 2013). Although it is necessary to consider open innovation holistically, detailed study of its practices is important for understanding its effect on performance. We also contribute to the literature that promotes studying supply network enabled innovation, rather than drawing conclusions by focusing on a specific supplier (Narasimhan and Narayanan, 2013).

The results of the moderating variables used in this study contribute to developing the literature on quality management and open innovation. We contribute generally to the literature that rejects relating quality and innovation in a simple way. Our results support the study by Pekovic and Galia (2009), which indicates the importance of examining how the organization uses its resources to obtain advantage in innovation with commitment to quality. This study shows, then, the advisability of analyzing the relation between quality and open innovativeness, opening a line of research within the general line that relates quality and innovation, a line that examines complementarity between the organization's resources and capabilities oriented to innovating openly, and its supply network. This study thus highlights the fundamental role that information technologies play in the study of this new paradigm in a context of quality improvement. Organizations that have implemented ISO 9000 standards and are oriented to open innovation must be supported by these information technologies, seeking their integration with partners with whom they put this orientation into practice to achieve better innovation performance.

We thus contribute to developing the literature on the relationship between open innovation and quality by demonstrating the organization's need to fit its resources and capabilities to its innovation sources in order to compensate for the possible shrinking of innovation performance implicit in this quality management system.

Managerial implications

Our results provide guidelines for managers to follow when putting open innovation into practice showing that the benefit obtained from it will depend, however, on the context of the organization. Implementing ISO standards does not impede achieving performance as a result of open innovativeness, but performance is lower and is conditioned by other factors. The coexistence of open innovativeness and quality requires complementarity of learning styles and, most importantly, compatibility of information technologies between the organization and the source with which the organization practices open innovation. This compatibility is essential to successful innovation performance in organizations with the ISO 9000 standard.

These factors are not crucial for uncertified organizations, but certified organizations must ground their actions in the aspects that, first, strengthen information technology integration to achieve improvement in their innovative performance and, second, balance exploratory and exploitative styles, achieving ambidexterity in their relationships with their supply network.

Managers must stimulate the creativity of their supply network and, on the internal level, establish a process for coupled creation with this network. More generally, they must also foster a culture that permits permeability of their boundaries with the exterior, eliminating internal barriers that impede benefitting from the adoption of open innovation in their organization.

Limitations and future research

Despite its contributions, this study has some limitations that must be taken into account. The first is the use of self-reported and single-respondent data. A single informant per organization participated in the survey and answered all questions for this research. It would be fruitful for future studies to attempt to obtain data from multiple respondents within a firm to minimize the potential impact of common method bias.

Second, implementation of ISO 9000 was measured as a categorical variable, which prevents us from taking into account the simultaneity of other quality management initiatives (e.g., Six Sigma, TQM). As Sisodiya et al. (2013) argue, open innovation is a complex phenomenon that may be influenced by other factors that we have not taken into account in this study. Knowledge of open innovativeness would be enriched by using longitudinal instead of cross-sectional data.

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IT INFRASTRUCTURE VERSUS COMPETITIVE AGGRESSIVENESS IN EXPLAINING AND PREDICTING GREEN-BASED VALUE CREATION

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Abstract

This research examines the impact of information technology (IT) infrastructure capability (an IT/internal variable) and industry competitive aggressiveness (an external variable) on green supply chain management capability and firm performance. We test the proposed research model by using the partial least squares (PLS) method of estimation on a survey and secondary data set from 203 large firms in Spain. Results suggest that: (1) IT infrastructure capability enables and industry competitive aggressiveness motivates firms to pursue a greener supply chain management to increase firm performance, (2) industry competitive aggressiveness has greater influence than IT infrastructure on firm's green-based value creation.

Keywords: IT infrastructure capability, competitive aggressiveness, environmental sustainability.

Introduction

Firms execute environmental management activities to reduce impact of their activities on the natural environment while simultaneously saving costs and increasing revenues (Benitez et al. 2015, Saeidi et al. 2015). This has been called the win-win philosophy because both the natural environment and the firms win with the execution of these firm's environmental management activities (Zhu and Sarkis 2004).

Information technology (IT) can be one problem and the solution for environmental sustainability (Wang et al. 2015). As one problem, IT is a source of environmental contamination during product manufacturing, usage and disposal, and it is responsible for approximately 2% of global greenhouse gas emissions. As the solution, IT may enable firms to increase their efficiency of resource use at firm and supply chain levels (Elliot 2011). Despite the IT-based opportunities to execute the firm's environmental management activities, the understanding of the role of IT in environmental sustainability is in its initial stages (Benitez et al. 2013, Wang et al. 2015). Prior research on Information Systems (IS) and Operations Management has paid significant attention to understand how IT enables the firm's supply chain management capabilities to improve firm performance (e.g., Devaraj et al. 2007, Setia and Patel 2013). However, research on the role of IT in enabling green supply chain management is very limited.

Firm's ability in using and leveraging the IT resource base for business activities (i.e., IT infrastructure capability) may improve the firm's coordination with the supply chain to achieve environmental management goals (i.e., green supply chain management) (Dao et al. 2011). Similarly, a firm that operates in an industry with a high degree of competitive aggressiveness may search to exploit new opportunities to save costs and increase revenues such as executing environmental management activities (Bose and Pal 2012). This research examines the relationships between IT infrastructure capability, competitive aggressiveness, green supply chain management and firm performance. The central thesis of this study is that IT infrastructure capability and competitive aggressiveness impact firm performance through green supply chain management, suggesting an indirect effect (i.e., a mediation effect) of green supply chain management. Specifically, this research has interest in comparing the effects of IT infrastructure capability (an IT/internal variable) and industry competitive aggressiveness (an external variable) on the development of a green supply chain management capability.

This is a paper positioned in the field of IS, one of the subfields of Decision Sciences. Consequently, the study of the impact of IT on firms and individuals is the critical research question. Specifically, this is a paper positioned in the IS literature on IT and firm performance, and IT and environmental sustainability. In this sense, IT infrastructure capability is the natural starting point. As a potential differential factor, this paper includes industry competitive aggressiveness to the proposed research model. Also, because the competition in the market is now at the supply chain level (instead of at firm level), this research examines the impact of IT on environmental sustainability at the supply chain level by focusing on green supply chain management capability (e.g., Zhu and Sarkis 2004).

Hypotheses and proposed research model

IT infrastructure capability and green supply chain management

IT infrastructure capability is the firm's ability to leverage its technological, managerial and technical IT resources to perform/execute business activities (Benitez and Walczuch 2012, Chen et al. 2014). While technological IT resources include servers, computers, laptops, operating systems, software, electronic communication networks (email, Intranet, wireless devices) and shared customer databases, managerial/technical IT resources are the business and technical skills of IT managers/employees respectively (Benitez and Ray 2012). IT infrastructure is a higher-order capability determined by technological IT infrastructure, managerial IT infrastructure and technical IT infrastructure capabilities (Melville et al. 2004).

Supply chain management refers to the bunch of activities associated with information and material flow up and down the supply chain (network of suppliers, distributors and customers) (Bose and Pal 2012). Green supply chain management refers to all environmental management activities monitored within the supply chain to improve the firm's environmental performance (Zhu and Sarkis 2004). Green supply chain management indicates the firm's ability in adopting and integrating environmental management activities into the supply chain to both reduce the impact of the supply chain on the natural environment and increase firm performance (Green et al. 2012). This operational capability has an external component in collaboration with suppliers (i.e., green purchasing practices) and customers (i.e., reverse logistics), and an internal component related to the internal execution of environmental management practices in the manufacturing and logistics operations (i.e., eco-design, green manufacturing practices and investment recovery) (Zhu and Sarkis 2004, Green et al. 2012). Greening the supply chain aims to maximize value over life cycle of a product and at the end of its use (Mitra and Datta 2014).

IT infrastructure may enable the development of a green supply chain management capability. Firms that leverage the technological, managerial and technical IT base to run cutting-edge business applications might be better capable to coordinate with both suppliers and customers to execute environmental management activities (Benitez and Walczuch 2012). Similarly, leveraging IT infrastructure enables the digitalization of the firm's manufacturing processes which may increase the firm's efficiency in using resource internally, and to execute green manufacturing practices (Benitez et al. 2013, Wang et al. 2015). These green manufacturing practices are also part of the green supply chain management (Zhu and Sarkis 2004). We therefore hypothesize that:

Hypothesis 1 (H1): There is a positive relationship between IT infrastructure capability and green supply chain management.

Competitive aggressiveness and green supply chain management

This study further examines the role of competitive aggressiveness in developing a green supply chain management capability. Competitive aggressiveness refers to the extent to which firms experience competitive attacks that are high in volume, duration, complexity and unpredictability from their industry key competitors (Ferrier 2001, Chen et al. 2015a). Firms that experience a high degree of competitive aggressiveness may be motivated to develop a green supply chain management capability. A firm can take actions motivated by signals sent by the rivals (Dai et al. 2015). In that sense, it can be reasonably argued that firms that experience long, complex, unpredictable and large number of competitive attacks from key competitors search for new business opportunities to survive in the long run. Since the competition may be extended to the supply chain, firms operating in competitive aggressiveness industries are willing to integrate environmental management activities into their supply chain in order to reduce uncertainty and remain competitive in the long run (Mignerat and Rivard 2009). This particularly holds true if customers demand their suppliers to contribute to an environmentally sustainable development. Hence, we hypothesize that:

Hypothesis 2 (H2): There is a positive relationship between competitive aggressiveness and green supply chain management.

Green supply chain management and firm performance

Green supply chain management may increase firm performance. The execution of green supply chain management practices does not have to necessarily increase costs. Firms must comply with environmental law. Designing and executing green supply chain management practices beyond environmental law is a business/operational strategy voluntarily implemented by some firms, which implement these practices to both reduce the impact of the supply chain on the natural environment and create green-based value (i.e., any positive impact on any variable of firm process/performance). For example, cross-functional cooperation for environmental improvements may reduce the consumption of raw materials to save costs (Benitez and Walczuch 2011, 2012). Similarly, collaborative activities with suppliers (i.e., green purchasing) and customers (i.e., reverse logistics) improve customer satisfaction, firm's reputation and brand value, which in turn increase revenues and consequently it provides a higher firm performance. Prior research in Operations Management (e.g., Bose and Pal 2012, Green et al. 2012) finds a positive relationship between green supply chain management and firm market performance. There is also some anecdotal evidence that suggests a positive relationship between green supply chain management and firm performance. For example, Mercadona (a leading Spanish retailer) works very close and on a long term base with its suppliers. Mercadona, in cooperation with its strategic suppliers, has reduced the size of packaging of its home brand products (developed by one strategic supplier) to cut costs and increase firm performance, as well as to reduce the impact of the supply chain on the natural environment (Ton and Harrow 2010, Benitez et al. 2015). Similarly, Xerox Corporation and Siemens show successful business benefits in take-back programs by refurbishing and remanufacturing pre-owned equipment (i.e., Xerox Corporation saves annually 200 million U.S. dollars by remanufacturing products). Finally, PerkinElmer (a global technology firm that develops advanced precision instruments for health and environmental sciences) implements end-of-life management practices (i.e., reuse, remanufacturing, recycling or disposal) to make the most of old instruments. PerkinElmer motivates customers to contribute in a responsible management of product life. Customers who return their equipment to the firm receive a 10% discount in the next purchase. In return, PerkinElmer helps to reduce the environmental impacts of products, as well as improves customer relations, inhibits competitors to refurbish and resell their equipment, and reduce processing cost (i.e., remanufacturing costs are lower that manufacturing new equipment) (Veleva et al. 2013). Based on this discussion, we hypothesize that:

Hypothesis 3 (H3): There is a positive relationship between green supply chain management and firm performance.

Research methodology

Data and sample

This study uses a combination of survey and secondary data in 203 large firms in Spain. We measure IT infrastructure capability, competitive aggressiveness, green supply chain management, strategic flexibility and quality management (i.e., control variables) with survey data. This research measures firm performance and firm size (i.e., control variable) with information collected from *Actualidad Economica* database (http://www.actualidadeconomica.com/) (Benitez and Ray 2012, Benitez et al. 2015). We designed a questionnaire, wherever possible, by adapting measurement items from existing scales. This questionnaire was tested by 15 faculty members and through a pilot test with eight IT/business executives. We sent the final version of the questionnaire by mail and email to senior IT and business executives in 1046 large firms included in the 2007 edition of the *Actualidad Economica* database. Several reminders were sent by email and a final reminder by phone. This data collection process performs from December 2007 to April 2008. We received a total of 203 valid questionnaires, giving an effective response rate of 20.24%. This response rate can be considered as satisfactory and is consistent with those obtained in prior literature (e.g., Byrd and Davidson 2003, Lawson et al. 2015). This study measures firm performance and firm size with information collected from *Actualidad Economica* database for those firms that complete a valid questionnaire (Benitez and Ray 2012). We assess non-response bias by verifying that early and late respondents do not differ in their responses. All possible t-test comparisons between the means of the two groups of respondents show non-significant differences. Firms of the sample come from firms in 25 different industries: wholesale (39 firms, 19.21%), real estate and/or construction (35 firms, 17.24%), chemical (15 firms, 7.39%), communications and graphic design (7.39%), retail (12 firms, 5.91%), non-metal mining (10 firms, 4.93%), consulting (9 firms, 4.43%), food and beverages (8 firms, 3.94%), and other industries (60 firms, 29.56%).

Measures

We measure IT infrastructure capability as a composite second-order construct determined by technological IT infrastructure, managerial IT infrastructure and technical IT infrastructure capabilities. Technological IT infrastructure capability is measured through annual IT investment on IT infrastructure and specific business applications per employee (Ray et al. 2005). The constructs managerial and technical IT infrastructure capabilities are measured using four indicators (each construct) adapted from Byrd and Davidson (2003), and Ray et al. (2005).

We measure competitive aggressiveness with four new indicators based on the conceptual underpinnings of Ferrier (2001), which focus on the volume, duration, complexity and unpredictability of competitive attacks of each firm's key competitors in its industry. Green supply chain management is measured with seven indicators adapted from Zhu and Sarkis (2004). Firm performance is specified and measured as a composite first-order construct determined by the rate of sectoral excellence (RSE) for years 2007-2011, with information collected from Actualidad Economica database for the years 2007-2011. RSE is an objective and robust measure of firms' sectoral positioning (Benitez and Walczuch 2012, Benitez and Ray 2012). The RSE is estimated from secondary data contained in any known ranking of firms in the following way: RSE = 1 - (Ranking position of firm / Total number of firms in the industry). In our case, the RSE is calculated based on sales ranking of the firm in their specific industry. The RSE will range from 0 to 1 (termed the industry's maximum value). The closer the RSE is to this maximum value for the industry, the better is the firm's competitive position and performance (Benitez et al. 2015).

This study controls for firm size, strategic flexibility and quality management on firm performance. Firm size is measured through the natural logarithm of the number of employees (Benitez and Ray 2012). Strategic flexibility is measured by using four indicators created based on the Volberda's (1996) insights with survey data. Quality management is measured through a two indicators adapted from Zhu and Sarkis (2004) with survey data. All the constructs are specified as composite/formative at both first- and second-order levels (Henseler 2015).

Empirical analysis

This study uses the variance-based structural equation modeling (SEM) technique and the partial least squares (PLS) method of estimation to test the hypotheses and examine the indirect effects involved in the proposed research model. This study uses the statistical software package Advanced Analysis for Composites (ADANCO) 1.1.1 Professional (http://www.composite-modeling.com/) (Henseler and Dijkstra 2015). ADANCO is particularly useful to estimate models that contain composite constructs, as in this study (Henseler et al. 2016).

It is appropriate to use PLS approach in this study for the following reasons. First, PLS is a full-fledged SEM approach that can test for exact model fit and works very well in explanatory and predictive research, as this study (Chin 2010, Shmueli and Koppius 2011, Hair et al. 2012, Henseler et al. 2016). Second, all the constructs specify as composite, and PLS is a suitable method for obtaining robust results with this type of constructs (Gefen et al. 2011, Hair et al. 2012, Henseler et al. 2014). Third, the use of PLS SEM is advisable to estimate models that employ secondary data (Gefen et al. 2011, Benitez and Walczuch 2012). Fourth, PLS SEM is suitable to achieve better results with complex models (i.e., with a large number of indicators or multidimensional constructs) as in this study, comparing with covariance-based SEM techniques (Hair et al. 2012, Roldan and Sanchez 2012). Finally, PLS is a variance-based SEM technique that has become well established in IS research literature because many of the concepts are not directly observable (Roldan and Sanchez 2012, Benitez et al. 2015, Braojos et al. 2015a, 2015b, Chen et al. 2015b). To estimate the level of significance of weights, loadings and path coefficients, we run the bootstrapping algorithm with 5000 subsamples (Petter et al. 2007, Barroso et al. 2010, Hair et al. 2011).

Measurement model evaluation

We evaluate the content validity, multicollinearity, weights and loadings for the composite constructs (Cenfetelli and Bassellier 2009). First, we assess whether the indicators of all first-order constructs and the dimensions of second-order constructs capture the full domain of the constructs. To this end, we ensure that the indicators and dimensions have content validity by using validated scales and by pre-testing the questionnaire with 15 faculty members and eight IT/business executives.

After the data collection, we examine multicollinearity by calculating variance inflation factors (VIFs) at the first- and second-order level. All VIF values are below 3.3 at first- and second-order levels and thus do not indicate serious multicollinearity problems (Petter et al. 2007, Roberts and Thatcher 2009, Roldan and Sanchez 2012). After that, we examine whether the weights and loadings of indicators and dimensions are significant (Benitez and Ray 2012). All indicator and dimension weights and loadings are significant at 0.001 level. The second-order constructs are calculated by performing the two steps approach (Chin 2010). Table A1 (in the appendix) provides detailed information on the VIF values, weights and loadings of the indicators and dimensions. Table A2 presents the correlation matrix.

Finally, we assess the external validity of all composites by means of confirmatory composite analysis. We evaluate the goodness of model fit for the measurement models of the first (i.e., first-order level) and second steps (i.e., second-order level) by examining the standardized root mean squared residual (SRMR), unweighted least squares (ULS) discrepancy (d_{ULS}) and geodesic discrepancy (d_G) (Henseler et al. 2014). All these goodness of fit measures evaluate the discrepancy between the empirical correlation matrix and the model-implied correlation matrix (Henseler 2015). The lower the SRMR, d_{ULS} and d_G the better the fit of the research model (Henseler and Dijkstra 2015). For the measurement models of both the first- and second-order steps, all discrepancies are below the 95%-quantile of the bootstrap discrepancies, which means that these models should not be rejected based on an alpha level of 0.05 (Table 1). Overall, the evaluation of the measurement models at all levels and steps suggests that there is empirical support for the structure of composites and that the study measures have very good measurement properties.

Table 1 – Measurement model fit evaluation

Discrepancy	**First step**			**Second step**		
	Value	HI_{95}	Conclusion	Value	HI_{95}	Conclusion
SRMR	0.05	0.10	Supported	0.07	0.11	Supported
d_{ULS}	0.87	2.91	Supported	1.83	3.84	Supported
d_G	0.45	1.40	Supported	0.51	1.16	Supported

Test of hypotheses

We test the proposed research model by performing a PLS estimation and analyzing the effect size (f^2) for the hypothesized relationships. f^2 values of 0.02, 0.15 and 0.35 indicate a weak, medium or large effect size of adding a link between an exogenous and endogenous variable (Henseler and Fassott 2010). Thus, we examine the beta coefficients, level of significance, and R^2 and f^2 values to test the hypotheses. Figure 1 presents the results of the PLS estimation. Table 2 provides the analysis of the effect size for every relationship included in the proposed model. The empirical analysis supports H1, H2 and H3. There is a positive relationship between IT infrastructure capability and green supply chain management capability ($\beta = 0.26^{***}$). Competitive aggressiveness has also a positive relationship with green supply chain management ($\beta = 0.40^{***}$). Finally, we also find a positive relationship between green supply chain management and firm performance ($\beta = 0.21^{**}$). As per the control variables, firm size and strategic flexibility seem to also increase firm performance (0.001 level).

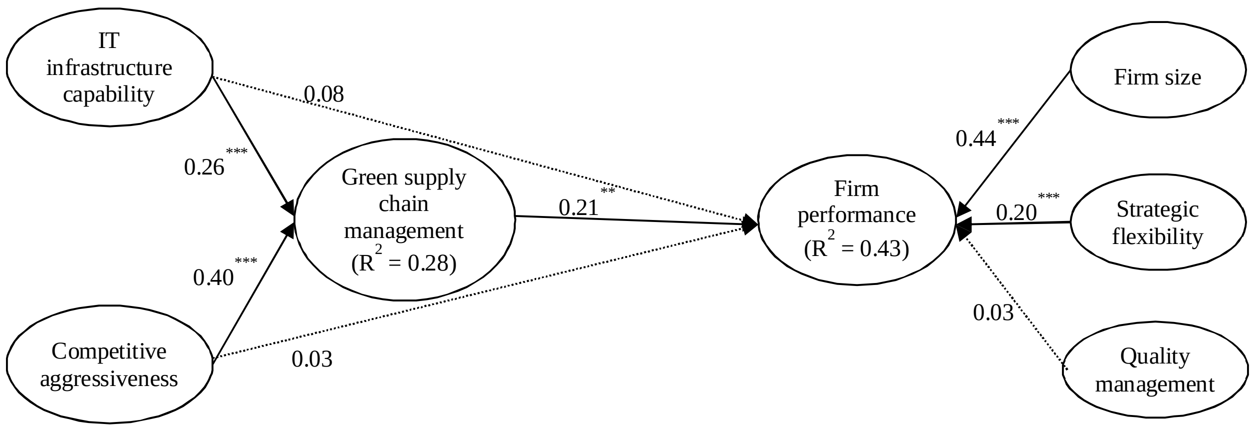

Figure 1 – Results of the PLS estimation ($^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, one-tailed test)

Table 2 – Effect size analysis

Relationship	**f^2 value**	**Effect size**
Hypothesized relationship	**f^2 value**	**Effect size**
IT infrastructure capability → Green supply chain management (H1)	0.08	Weak-medium
Competitive aggressiveness → Green supply chain management (H2)	0.20	Medium-high
Green supply chain management → Firm performance (H3)	0.05	Weak-medium
Control variables	**f^2 value**	**Effect size**
Firm size → Firm performance	0.30	High

Strategic flexibility → Firm performance	0.06	Weak-medium
Quality management → Firm performance	0.00	Very weak

The values of the beta coefficients, their level of significance, the f^2 values and the R^2 values are individual measures of the explanatory power of the model (Shmueli and Koppius 2011). Beta coefficients around 0.2 are economically significant, and R^2 values higher than 0.2 indicate good explanatory power of the endogenous variables of the model (Chin 2010, Benitez and Ray 2012). The beta coefficients of the hypothesized relationships in the proposed research model range from 0.21^{**} to 0.40^{***}. The f^2 values links involved in the hypothesized relationships range from 0.05 and 0.20. The effect size analysis suggests that the industry competitive aggressiveness (f^2 = 0.20) has a greater influence than IT infrastructure capability (f^2 = 0.08) in explaining the development of a green supply chain management. The R^2 values for these relationships range from 0.28 to 0.43. Overall, this analysis suggests a good explanatory power for the proposed research model.

When assessing the predictive power of the proposed research model, a critical question refers to whether or not the model predicts all dependent variables in an additional holdout sample (Gigerenzer and Brighton 2009, Woodside 2013). To evaluate the predictive validity of the proposed research model, this study randomly splits the data set into two sub-samples (n = 142/61) (Gigerenzer and Brighton 2009). While the larger sample functions as estimation sample, the smaller sample represents the holdout sample. A model estimation using the estimation sample eventually generates weights and beta coefficients that are used to predict all dependent variables in the holdout sample. The comparison of the predicted and "observed" values indicates how well the proposed research model performs in terms of predictive validity. Table 3 provides the correlation values (r), the calculated r^2 of the holdout sample, as well as the R^2 of the full sample. These findings suggest that the proposed research model shows adequate predictive validity.

Table 3 – Predictive validity analysis

	Green supply chain management	**Firm performance**
r	0.69	0.76
r^2	0.48	0.58
R^2	0.28	0.44

Finally, we also evaluate the goodness of model fit for the structural models at first- and second-order levels by examining the SRMR, unweighted least squares (ULS), d_{ULS} and d_G values (Henseler et al. 2014). All discrepancies are below the 95%-quantile of the bootstrap discrepancies, which means that these structural models should be accepted based on an alpha level of 0.05 (Table 4). Overall, the evaluation of the structural models at all levels and steps suggests that there is good structural model fit.

Table 4 – Structural model fit evaluation

Discrepancy	**First step**			**Second step**		
	Value	HI_{95}	Conclusion	Value	HI_{95}	Conclusion
SRMR	0.05	0.10	Supported	0.05	0.09	Supported
d_{ULS}	0.87	2.91	Supported	0.99	2.49	Supported
d_G	0.45	1.40	Supported	0.48	1.08	Supported

Mediation analysis

We perform a mediation analysis to examine the mediation effects involved in the proposed research model. Specifically, we include in the proposed model a link between: (1) IT infrastructure capability and firm performance, and (2) competitive aggressiveness and firm performance. The direct effects of these two links are not significant (0.08 and 0.03) while their indirect effects are significant (0.05* and 0.08**), which reinforces the results obtained in the test of hypotheses, and suggests that the effects of IT infrastructure capability and competitive aggressiveness on firm performance through green supply chain management are significant (Zhao et al. 2010). Table 5 provides the details of this mediation analysis.

Table 5 – Mediation analysis

Relationship	Direct effect	Indirect effect
IT infrastructure capability → Firm performance	0.08	0.05*
Competitive aggressiveness → Firm performance	0.03	0.08**

Qualitative comparative analysis

The construct IT infrastructure capability is operationalized as a composite second-order construct determined by technological, managerial and technical IT infrastructure capabilities. While the PLS estimation considers the net effect of the second-order construct on the dependent variable, we additionally examine whether different configurations of the first-order dimensions of IT infrastructure capability cause high levels of green supply chain management. To this end, we apply the configurational approach fuzzy set qualitative comparative analysis (fsQCA) which allows controlling for equifinality (Fiss 2011, Woodside 2013). Equifinality implies that several causal paths may exist to an outcome (Fiss 2011). FsQCA comprises the following three steps: (1) transformation of measures into fuzzy set membership scores, (2) construction and refinement of the truth table, and (3) analysis of the sufficient conditions for the outcome of interest (Fiss 2011). When transforming the measures into fuzzy set membership scores, we use the unstandardized latent variables scores for the multiple-item measurement constructs. For the constructs managerial IT infrastructure, technical IT infrastructure and green supply chain management use 6 as anchor point for full membership, 2 for full non-membership, and 4 as crossover point (Ordanini et al. 2014). For the single-item construct technological IT infrastructure, use 21% as anchor point for full membership, 1% for full non-membership and 11% as crossover point. When redefining the truth table, we set 2 as cut-off value for minimum number of cases per solution and 0.90 as cut-off value for minimum consistency level of a solution. The analysis of the complex, parsimonious and standard solution term leads to the same configurations. While the overall solution coverage is 0.43, the overall solution consistency is 0.87. The fsQCA performed to analyze causes for a high level of prediction of green supply chain management eventually reveals two distinct configurations of the dimensions of IT infrastructure capability. These two configurations are: (1) the presence of technological and managerial IT infrastructure, and (2) the presence of technological and technical IT infrastructure. The presence of technological IT infrastructure in both solutions indicates its prominent role as a critical dimension to evaluate and measure IT infrastructure capability, which is consistent with prior IS research (e.g., Melville et al. 2004).

Discussion and conclusions

This research examines the relationships between IT infrastructure capability, competitive aggressiveness, green supply chain management and firm performance. We test the proposed research model through a PLS estimation and find that: (1) IT infrastructure capability enables and industry competitive aggressiveness motivates firms to pursue a greener supply chain management to increase firm performance, (2) industry competitive aggressiveness has a greater influence than IT infrastructure capability in explaining and predicting firm's green-based value creation.

This research has also limitations. First, these findings should be generalized only to large firms in Spain. Future research can explore whether the theory and prediction of this research keep in small and medium firms from the entrepreneurial context of other countries. Second, although this study measures firm performance with a five year panel data, it measures IT infrastructure capability, competitive aggressiveness and green supply chain management with cross-sectional data. Future research may revisit the explanatory and predictive power of the proposed research model by using a panel data for all the variables involved in the model.

However, this research has three clear research contributions. First, our understanding of the IT impact on firm's environmental sustainability is in its initial stages, including the ongoing debate on the twofold role of IT as a problem and solution for environmental sustainability (e.g., Benitez et al. 2015, Wang et al. 2015). This study theoretically explains and empirically demonstrates that IT infrastructure capability enables firms to develop a green supply chain management capability to achieve superior firm performance. Firms leverage their technological, managerial and technical IT base to run cutting-edge business applications to coordinate with suppliers and customers to execute environmental management activities. In this sense, IT infrastructure leverages to become one possible solution for environmental sustainability at firm-level.

Second, this study finds support for the positive relationship between competitive aggressiveness and green supply chain management. Firms that experience a high degree of industry competitive aggressiveness are more motivated to integrate environmental management activities into their supply chain as one possible solution to survive in the long run. The empirical analysis suggests that industry competitive aggressiveness has a greater influence than IT infrastructure capability in explaining and predicting firm's green-based value creation. Third, this research provides a good practical application in research on IT and firm's environmental sustainability, and, thereby, illustrates the PLS path modeling usefulness in IS research.

Apart from deriving these important theoretical contributions, this research is of practical relevance. First, firm's investments in IT infrastructure provide the IT platform and IT knowledge to better coordinate with suppliers and customers to execute environmental management activities. In this sense, firms interested in pursuing a greener supply chain management should invest more in IT infrastructure and leverage better its IT infrastructure. Second, managing the supply chain in a more environmentally sustainable way enables firms to achieve superior performance. For example, practices such as recycling, remanufacturing and energy efficiency enable firms to save costs. Furthermore, collaborative green activities with customers (e.g., reverse logistics) improve customer satisfaction, firm's reputation and brand value, and, thus, may lead to increased sales and revenues.

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Appendix

Table A1 – Measurement model evaluation at first- and second-order level

Construct/indicator	VIF	Weight	Loading
Technological IT infrastructure	1.44	0.31***	0.69***
Annual IT investment per employee	1.00	1.00	1.00
Managerial IT infrastructure: 1: Strongly disagree, 7: Strongly agree	1.93	0.53***	0.91***
IT managers identify and support IT-enabled business activities	1.88	0.28***	0.81***
IT managers provide adequate funding to execute IT innovation projects	1.88	0.27***	0.80***
IT managers redesign IT processes to sense and respond to business opportunities	1.61	0.37***	0.82***
IT managers work closely with business managers to execute the firm’s business strategies	1.94	0.31***	0.84***
Technical IT infrastructure: 1: Strongly disagree, 7: Strongly agree	1.43	0.40***	0.76***
Skills of our IT personnel in designing databases are excellent	2.05	0.31***	0.83***
Skills of our IT personnel in developing new IT applications are excellent	2.46	0.28***	0.87***
Skills of our IT personnel in improving the efficiency of the IT services are excellent	1.79	0.33***	0.82***
IT personnel know different programming languages	1.54	0.31***	0.77***
Competitive aggressiveness: Please indicate, on a scale of 1 to 7, the degree to which you agree or disagree with the following statements as they apply to your industry in the last 5 years: 1: Strongly disagree, 7: Strongly agree			
Key competitors typically carried out competitive attacks with a high number of competitive action events (e.g., pricing, new product development, capacity or service actions)	2.45	0.30***	0.88***
Key competitors typically carried out competitive attacks of long duration	2.03	0.30***	0.84***
Key competitors typically carried out competitive attacks with a broad range of types of competitive actions (complex repertoire of competitive actions)	2.66	0.28***	0.88***
Key competitors typically carried out unpredictable sequences of competitive moves	2.61	0.28***	0.87***
Green supply chain management: How would you evaluate your firm’s ability to implement the following green supply chain management practices when they are perceived to be useful to create business and/or environmental value? 1: Poor, 4: Good, 7: Excellent			
Commitment and support for green supply chain management from managers	2.50	0.19***	0.83***
Cross-functional cooperation for environmental improvements	2.57	0.18***	0.84***
Design of products for reduced consumption of material/energy	2.11	0.17***	0.79***
Environmental management system exists	2.50	0.19***	0.84***
Collaboration with suppliers on environmental issues	2.33	0.21***	0.83***
Cooperation with customers on environmental issues	2.02	0.14***	0.76***
Making decisions about ways to reduce overall environmental impact of our products	2.06	0.15***	0.78***

Firm performance			
RSE 2007	1.88	0.36^{***}	0.85^{***}
RSE 2008	2.01	0.23^{***}	0.81^{***}
RSE 2009	2.18	0.23^{***}	0.83^{***}
RSE 2010	2.13	0.23^{***}	0.81^{***}
RSE 2011	1.89	0.17^{***}	0.75^{***}
Strategic flexibility			
Our firm changes current strategies quickly with low costs	2.82	0.30^{***}	0.89^{***}
Our firm can increase with ease the variety of products for delivery	2.29	0.28^{***}	0.85^{***}
Our firm can enter in new markets for delivery	1.62	0.31^{***}	0.79^{***}
Our firm periodically adopts new technologies	2.86	0.29^{***}	0.89^{***}
Quality management: How would you evaluate your firm's (degree of) implementation of the following quality management practices? 1: Not considering it, 2: Planning to consider it, 3: Considering it currently, 4: Implementation will begin in the short term, 5: Initiating implementation currently, 6. Intermediate implementation phase, 7: Implementing successfully			
ISO 9000 serial certification	1.19	0.57^{***}	0.82^{***}
Total Quality Management type programs	1.19	0.62^{***}	0.85^{***}

Table A2 – Correlation matrix

Construct	1	1.1	1.2	1.3	2	3	4	5	6	7
1. IT infrastructure capability	1.00									
1.1. Technological IT infrastructure	0.69***	1.00								
1.2. Managerial IT infrastructure	0.91***	0.55***	1.00							
1.3. Technical IT infrastructure	0.76***	0.23***	0.54***	1.00						
2. Competitive aggressiveness	0.27***	0.21***	0.16**	0.26***	1.00					
3. Green supply chain management	0.36***	0.27***	0.24***	0.35***	0.47***	1.00				
4. Firm performance	0.24***	0.05	0.24***	0.25***	0.22***	0.41***	1.00			
5. Firm size	-0.02	-0.25***	0.15*	-0.01	0.07	0.19**	0.53***	1.00		
6. Strategic flexibility	0.39***	0.27***	0.23***	0.40***	0.13*	0.30***	0.40***	0.22***	1.00	
7. Quality management	0.11	0.11	0.06	0.11	0.27***	0.36***	0.27***	0.25***	0.18**	1.00

LOOKING FOR ORGANIZATIONAL ADAPTATION: SIX SIGMA, DYNAMIC CAPABILITIES AND FLEXIBILITY

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Abstract

In this paper, we analyze the relationship between Six Sigma, dynamic capabilities generation and organizational flexibility. To empirically test the relationships, we used data from 66 Six Sigma European firms. We employed structural equation modeling and additional tests to observe the mediating role of dynamic capabilities. Firstly, our results show a significant relationship between Six Sigma practices and dynamic capabilities generation. Secondly, a significant relationship between dynamic capabilities and flexibility –operational and strategic dimensions- has been also supported. Finally, our results confirmed that dynamic capabilities act as mediating variable in the relationship between Six Sigma practices and flexibility.

Keywords: Six Sigma, dynamic capabilities, competitive advantage

Introduction

The growing interest and importance of Six Sigma initiative has been recognized in recent years attracting attention in both business and academia (McAdam and Hazlett, 2010; Nonthaleerak and Hendry, 2008). Despite this interest, the literature lacks a comprehensive approach to explain the link between Six Sigma and key variables of strategic management, such as performance or competitive advantage. The results of recent empirical research yield contradictory findings to explain how Six Sigma affects performance (e.g., Gutiérrez et al., 2012; Mellat, 2011; Nair et al., 2011). The studies agree primarily on the positive effects of Six Sigma on operating issues such as cost savings and defect reduction (see Choi et al., 2012; Hilton and Sohal, 2012), whereas serious concerns remain about its long-term effects (Mellat, 2011; Nair et al., 2011; Swink and Jacobs, 2012). For example, some scholars agree that Six Sigma's intensive efficiency orientation could eventually damage other long-range variables, such as organizational growth (e.g., Mellat, 2011; Swink and Jacobs, 2012). Based on this premise, our empirical study analyses the effects of Six Sigma implementation on strategic variables, focusing on the concept of sustainable competitive advantage.

In the attempt to explain sustainable competitive advantage, the dynamic capabilities view (Teece et al., 1997) has emerged consistently as the starting point for a general theory of Strategic Management. It is considered to be one of the most vibrant and influential topics in current research (Schilke, 2013; Vogel and Guttel, 2012) and has even been proposed as a new Strategic Management paradigm (see Teece, 2007). In the research agenda of the dynamic capabilities view, scholars encourage micro-level analysis to shed light on the creation and action of dynamic capabilities. Many studies attempt to explain how marketing, human resources or operations strategies can trigger the creation of dynamic capabilities (e.g., Bruni and Verona, 2009). This new framework is based on the assumption that dynamic capabilities can be understood as the interaction of cross-functional processes to renew the resource base (Eisenhardt and Martin, 2000).However, more attention has been paid to operations management. The inherently technical nature of some dynamic capabilities, such as *new product development*, highlights the fact that the role of operations management is essential to understanding how dynamic capabilities are employed.

In response to these recent research questions, our paper pursues a twofold objective. On the one hand, we aim to demonstrate that Six Sigma can be closely connected to strategic issues, beyond its expected operational results. To determine this, we analyse whether Six

Sigma implementation can be related to dynamic capabilities and strategic and operational flexibility, thereby showing a close connection to variables that provide a sustainable competitive advantage. On the other hand, as to the dynamic capabilities agenda, our goal is to provide empirical evidence to show that the development of successful dynamic capabilities can enhance the effects of functional best practices, such as Six Sigma initiatives.

This study contributes to the literature in various ways. First, our findings provide empirical evidence for prior studies that focus on the long-term value of Six Sigma, which has not received solid, rigorous statistical analysis (Choi et al., 2012). Second, in response to some scholars' research calls (e.g., Bruni and Verona, 2009; Teece, 2007), we analyse the link between a specific operations management strategy and dynamic capabilities generation. Third, although other empirical papers have demonstrated the positive effect of Six Sigma on performance through its influence on dynamic capabilities, none of the previous empirical papers has measured the generation of dynamic capabilities (see Gowen and Tallon, 2005; Swink and Jacobs, 2012). Furthermore, building on recent recommendations in the literature, we have used the most consolidated underlying components of dynamic capabilities to develop an accurate measurement model (e.g., Barreto 2010). Additionally, our analysis contributes to other studies that confirm the role of dynamic capabilities as mediating variable between functional best practices and evidence of competitive advantage (e.g., Hsu and Wang, 2012). Our study also is relevant to practitioners because our results support the decision to implement Six Sigma. Key Six Sigma practices are identified for those managers who wish to foster dynamic capabilities generation inside their companies. This research also contributes to the search for sustainable competitive advantage by offering a potential model for managers looking for organizational success.

Six Sigma and the dynamic capabilities view

Six Sigma

Schroeder et al. (2008, p. 540) recently defined Six Sigma as "an organized, parallel-meso structure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives". Despite this success, Six Sigma was originally criticized for not contributing new and different ideas to quality management. However, recent studies make strong arguments for its discriminant validity with respect to other quality management systems (e.g., Easton and Rosenzweig, 2012; Schroeder et al., 2008; Swink and Jacobs, 2012; Zu et al., 2008). These studies show that Six Sigma includes innovative practices that make it an extremely valuable practice. For instance, Zu et al. (2008) propose an integrative model to discriminate between traditional quality management practices and specific Six Sigma practices, identifying three specific features of Six Sigma: role structure, structured improvement procedure and focus on metrics. According to these studies, our analysis has focused on two practices that describe specific features of Six Sigma. These practices are *teamwork management* and *statistical metrics usage*. Teamwork management refers to the role of team managers (Black Belts) to promote the exchange of ideas and opinions, team mentality and individual motivation. Statistical metrics usage is made up of statistical process control (SPC) and other statistical tools to improve products and processes.

Dynamic capabilities view

According to Teece et al. (1997), dynamic capabilities indicate the firm's abilities to integrate, construct and reconfigure internal and external competences to respond to competitive environments. Thus, research on dynamic capabilities underscores the importance of firms' adaptation to changing external conditions (Kor and Mesko, 2013). Due to their dynamic nature, these capabilities explain how firms are able to maintain their competitive advantage in highly competitive environments.

Following Eisenhardt et al. (2010), *microfoundational* perspective of dynamic capabilities helps us to understand which underlying individual- and group-level actions promote their generation. Although the literature has identified real dynamic capabilities such as innovation, new product development and alliance and acquisitions management, the microfoundation of dynamic capabilities defines those common characteristics that facilitate the identification and measurement of any dynamic capability. The most recent empirical papers have employed these components satisfactorily, enabling more accurate comparison of their findings (e.g., Pavlou and El Sawy, 2011; Protogerou et al., 2012). Further, drawing on the microfoundation perspective, scholars need not consider dynamic capabilities as a black box but rather can explain the organizational capabilities on which dynamic capabilities are built. In this specific area, we highlight the importance of three main components: absorptive capacity, organizational learning and knowledge integration. Firstly, firms that have generated dynamic capabilities show outstanding absorptive capacity (Newey and Zahra, 2009; Wang and Ahmed, 2007). This capacity enables recognition of the value of external information and the sensing of new opportunities and threats. Secondly, organizational learning is required to assimilate such information and generate new knowledge (Nielsen, 2006). Several deliberate learning mechanisms have been proposed to explain how dynamic capabilities employ new information to change organizational resources and routines (Berghman et al., 2012; Zollo and Winter, 2002). Ultimately, knowledge integration is necessary to embed the new knowledge in organizational capabilities through regular exploitation activities (Nielsen, 2006; Verona and Ravasi, 2003). Thus, absorptive capacity, organizational learning and knowledge integration can be considered consolidated components of dynamic capabilities.

Development of hypotheses and proposed model

The fundamental role of dynamic capabilities is the renewal and reconfiguration of organizational routines based on organizational learning (Winter, 2003; Zollo and Winter, 2002). Therefore, dynamic capabilities are generated in those organizations in which employees are encouraged to develop trial and error tests, improvisation and imitation (Zahra et al., 2006) or are able to learn from past mistakes and pace of experience (Eisenhardt and Martin, 2000). According to prior studies, Six Sigma provides a culture of learning and constant change which permits renewal of the knowledge embedded in organizational routines (e.g., Easton and Rosenzweig, 2012). Both empirical and theoretical papers on the specific Six Sigma practices also provide preliminary argumentation proposing teamwork management and statistical metric usage as triggers of the ideal architecture to create dynamic capabilities (see Choo et al., 2007; DeMast, 2006; McAdam and Hazlett, 2010). Specifically, Choo et al. (2007) develop an integrative framework to explain the methodological and contextual elements of Six Sigma that ensure a valuable context for sustainable quality advantage. These authors claim that supportive leadership and the use of statistical tools such as mapping or streamlining processes plays an important role facilitating learning and knowledge creation. These elements are equivalent to teamwork management and statistical metric usage. We thus posit that these specific practices of Six Sigma will be positively related to dynamic capabilities.

Hypothesis 1a. There is a positive relationship between Six Sigma teamwork management and dynamic capabilities.

Hypothesis 1b. There is a positive relationship between Six Sigma and statistical metrics usage and dynamic capabilities.

Strategic flexibility will lead firms to respond rapidly and effectively to environmental shifts (Sanchez, 1995; Shimizu and Hitt, 2004; Volberda, 1996). In other words, strategic flexibility is the agility of top managers to reallocate and reconfigure resources, capabilities and processes (Eisenhardt and Martin, 2000). This agility can be supported and enhanced through dynamic capabilities such as alliance management and new product development. For example, alliance management could ensure strategic flexibility through external information and resource access (Young-Ybarra and Wiersema, 1999; Zollo and Singh, 2004). Likewise, new product development provides a regular reconfiguration of resources, processes and capabilities (Bruni and Verona, 2009; Newey and Zahra, 2009). Operational flexibility is related to the agility to reconfigure day-to-day tasks and routines (Volberda, 1996) and is defined as a “shop floor level" of flexibility (Pagell and Krause, 1999). This dimension includes abilities of customization, delivery flexibility, volume flexibility and manufacturing flexibility (Pagell and Krause, 2004; Sánchez, 1995). Indeed, operational flexibility can be considered the most immediate effect of dynamic capabilities, since their role is to change operating routines (Winter, 2003; Zollo and Winter, 2002). Operational flexibility thus defines the degree to which dynamic capabilities renew or modify organizational processes, routines, and capabilities. Bearing the foregoing in mind, we have formulated the following pair of hypotheses:

Hypothesis 2a. There is a positive relationship between dynamic capabilities and strategic flexibility.

Hypothesis 2b. There is a positive relationship between dynamic capabilities and operational flexibility.

Recent studies have focused their efforts on explaining how Six Sigma affects organizational performance or organizational learning. Additional contributions suggest, however, that Six Sigma can provide a source of adaptation (e. g., Gowen and Tallon, 2005; Padhy and Sahu, 2011; Swink and Jacobs, 2012). These contributions argue that some distinctive Six Sigma practices have great potential to promote constant change in culture and to respond to environmental shifts. However, the empirical results on this direct effect do not seem to be conclusive. Strategic and operational flexibility are complex variables that require other important internal and external factors. Strategic flexibility needs, for instance, speed of strategic change, variety of strategic options, applying new technologies (Sethi and Sethi, 1990; Volberda, 1996). Further, operational flexibility is derived from outsourcing, variation of production volume, temporary labour, etc. (Arias-Aranda et al., 2011; Sethi and Sethi, 1990; Volberda, 1996). Thus, it is quite difficult for a specific operations management strategy such as Six Sigma *perse* could improve the level of strategic and operational flexibility. However, other intermediate variables can intervene between Six Sigma practices and flexibility. Thus, dynamic capabilities can be proposed as the mechanism by which indirect effects of Six Sigma affect strategic and operational flexibility. In other words, when an organization creates dynamic capabilities, it can take advantage of Six Sigma practices to increase its strategic and operational flexibility. This is consistent with our previous argument to relate dynamic capabilities and flexibility. We can thus formally state the following hypotheses related to Six Sigma teamwork management and statistical metrics usage:

Hypothesis 3a: Dynamic capabilities mediate the relationship between teamwork management and strategic flexibility.

Hypothesis 3b: Dynamic capabilities mediate the relationship between teamwork management and operational flexibility.

Hypothesis 3c: Dynamic capabilities mediate the relationship between statistical metrics usage and strategic flexibility

Hypothesis 3d: Dynamic capabilities mediate the relationship between statistical metrics usage and operational flexibility.

Research methodology

To test the set of hypotheses, we developed an empirical study of European firms that had adopted Six Sigma. Data were collected through a structured questionnaire. We created a database of 350 European firms that had adopted Six Sigma. 66 valid responses were collected, achieving a response rate of 18.9%. Other prior Six Sigma studies have employed similar samples to test their hypotheses (e.g., Easton and Rosenzweigh, 2012; Gowen and Tallon, 2005). Nevertheless, we analysed possible bias due to non-respondent firms and found no significant differences in the organizational variables of responding and non-responding firms.

Results

The data analysis method used in this paper is structural equations modelling (SEM) with EQS 6.1. The results of structural model are detailed in Figure 1.

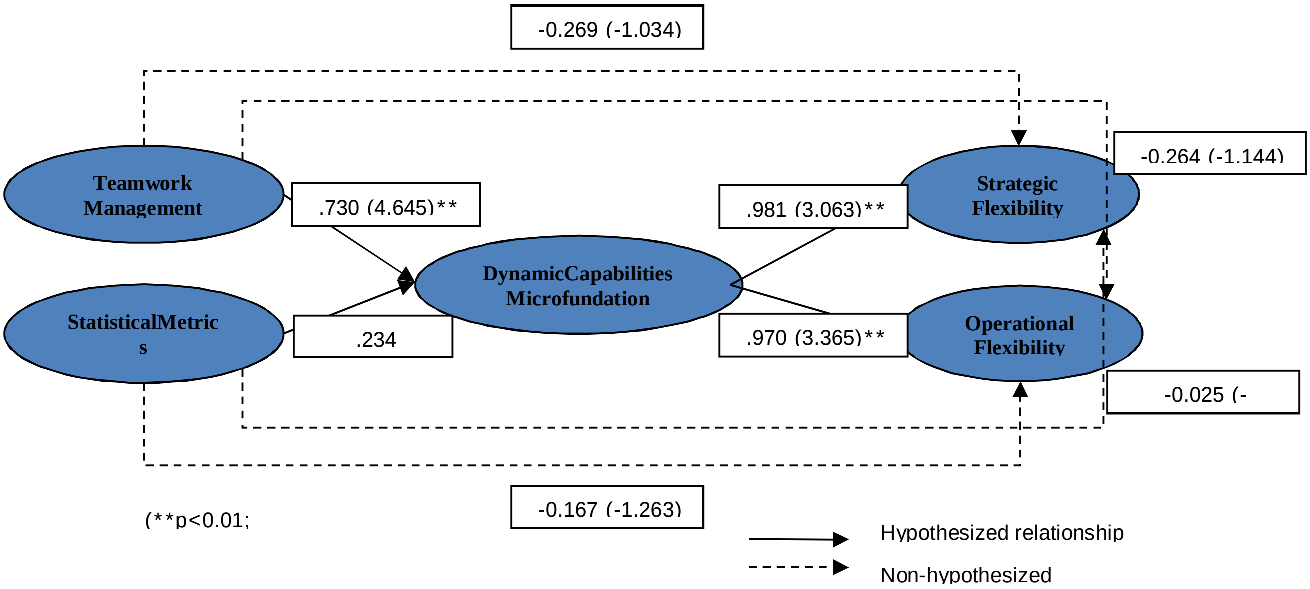

Figure 1. Proposed model

Firstly, the fit indices were: χ^2= 1,197.26, goodness of fit index (GFI) = 0.812, adjusted goodness of fit index (AGFI) = 0.728, normed fit index (NFI) = 0.971, comparative fit index (CFI) = 0.970, root mean square error of approximation (RMSEA) = 0.058. GFI, AGFI, NFI, and CFI above 0.5, and NFI and CFI above 0.9. These levels indicate satisfactory fit (Byrne, 1998; Mulaik et al., 1989).

Secondly, estimated parameters show a positive and significant relationship between specific practices of Six Sigma (teamwork management and statistical metrics usage) and Dynamic capabilities. These results support hypothesis H1a (0.730, t-value=4.645) and hypothesis H1b (0.234, t-value=2.012). In addition, as posited in hypotheses H2a and H2b, our results confirm a positive and significant relationship between dynamic capabilities and both dimensions of flexibility, strategic flexibility (0.981, t-value =3.063) and operational flexibility (0.970, t-value = 3.365).

Thirdly, to test hypothesis H3, we analysed the mediating role of dynamic capabilities, following the procedures proposed by several authors (e.g., Baron and Kenny, 1986; Preacher and Hayes, 2008) and observed how dynamic capabilities fully mediate the relationship of Six Sigma specific practices to strategic and operational flexibility.

Discussion

This study contributes to research on Six Sigma and dynamic capabilities in several ways. Firstly, we have confirmed empirically the relationship between Six Sigma implementation and strategic variables, such as dynamic capabilities and flexibility. These strategic variables have been used widely in the literature to explain competitive advantage and sustainable competitive advantage (see Cui and Jiao, 2011; Li and Liu, 2012). Secondly, we observe that strategic and operational flexibility can be also considered prospective effects of dynamic capabilities. Thirdly, the relationship between Six Sigma and adaptation can be explained through the development of dynamic capabilities. A high level of adaptation can be considered a preliminary foundation on which to build a sustainable competitive advantage.

The results of our findings on Six Sigma contribute to recent stream of the literature that tests its impact on organizational success. Whereas the literature strongly supports positive operational benefits derived from Six Sigma (see Choi et al., 2012; Hilton and Sohal, 2012), there is no general agreement regarding its long term effects or its implications for competitive advantage. Our results show a positive relationship between Six Sigma implementation and dynamic capabilities development. It has been demonstrated that Six Sigma can create a desirable learning infrastructure for developing dynamic capabilities. Few specific operations strategies have been considered so advantageous for organizational learning and adaptation. These results respond to some research calls from the dynamic capabilities literature to advance in the explanation of dynamic capabilities by using functional strategies (Easterby-Smith et al., 2009; Vogel and Guttel, 2012).

As to the link between dynamic capabilities and flexibility, our results support a positive relationship between dynamic capabilities and strategic and operational flexibility. Our work contributes to the dynamic capabilities view by explaining that firms that develop dynamic capabilities successfully can expect higher levels of strategic and operational flexibility. In addition, these findings add empirical evidence to previous studies that have proven flexibility capability to be an antecedent in achieving sustainable competitive advantage (e.g., Cui and Jiao, 2011).

Our research is also relevant in that it observes dynamic capabilities as mediating variable. Recent empirical studies have explained how dynamic capabilities enable other resources and capabilities to have an effective impact on strategic variables such as performance or competitive advantage (e.g., Hsu and Wang, 2012). Our results also confirm that dynamic capabilities fully mediate the relationship between Six Sigma practices and flexibility. This is a significant finding because it helps us to understand the nature of the relationship between Six Sigma and flexibility.

Finally, our study sheds light on a debate that has emerged recently within the Six Sigma literature. Several scholars claim that Six Sigma enhances behaviors that benefit primarily exploitation activities, damaging those related to exploration (Schroeder et al., 2008; Swink and Jacobs, 2012). However, our results demonstrate that Six Sigma is closely related to absorptive capacity, organizational learning and knowledge integration. Our study thus confirms that Six Sigma can generate an organizational learning structure that could contribute to both exploratory knowledge integration and exploitative activities. This result suggests that organizations may become more ambidextrous by implementing Six Sigma (Mellat, 2011; Schroeder et al., 2008).

Managerial implications

Results obtained provide important support for understanding the benefit derived from Six Sigma adoption. Whereas studies to date have primarily highlighted its operational benefits, our findings show how this initiative allows the organization to achieve additional strategic advantages. Also, managers seeking to develop knowledge-related capabilities such as absorptive capacity, organizational learning and knowledge integration may consider Six Sigma as an alternative that allows them to enhance these capabilities. Finally, the identification of the specific Six Sigma practices related to dynamic capabilities generation provides managers some practical guidelines on how to implement this initiative successfully.

Limitations and future lines of research

This study has certain limitations, but these limitations suggest new lines of research to advance in this area. Firstly, the firms included in the survey fulfill only the condition of having implemented Six Sigma projects. This limitation prevents us from analyzing additional information on the Six Sigma projects, such as current implementation stage, number of projects initiated, and number of specialists involved—information that could enrich our results substantially. Secondly, the data used are based on subjective perceptions from a single respondent. Future research could focus on this line, taking into account more respondents or objective data or developing case studies. Thirdly, this is a cross-sectional study. Due to the nature of dynamic capabilities, time-series or longitudinal data would be more appropriate for evaluating expected results, such as sustainable competitive advantage.

Conclusion

The findings presented here suggest that operations management strategies should be taken into account to achieve a better understanding of dynamic capabilities. Since Six Sigma practices have a positive influence on dynamic capabilities, the firm's resource and capabilities base could be influenced substantially by the adoption of Six Sigma. This fact has important implications for understanding the factors that lead to sustainable competitive advantage.

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GROUP VARIABLES AND INNOVATIVE PERFORMANCE: MEDIATING EFFECT OF THE TRANSACTIVE MEMORY SYSTEM

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Abstract

This study contributes to research on transactive memory systems (TMS) by analyzing the relationship between the group variables of trust (TRUST), collective mind (CM), and network ties (NT), as antecedents of innovative performance (IP), and the mediation effects of the TMS in these relationships. We propose a conceptual model grounded in seven hypotheses, tested through structural equations modelling (SEM) using EQS 6.1 software. The data analyzed are drawn from 257 Spanish university research-and-development (R&D) groups. Results show that TRUST, CM, and NT are positively associated with the TMS and that the TMS is positively related to DI. The most striking result is that the TMS performs a mediating role in the relationships of TRUST, CM, and NT to IP. The results support the conclusion that managers of university R&D groups should emphasize development of TMS to stimulate IP in groups and to make them more competitive.

Keywords: TMS, innovative performance, mediation

Main subject text

Innovation is currently a crucial element in the development of organizational productivity and competitiveness (Máñez et al., 2005; Delgado-Verde et al., 2011; Damijan et al., 2012; Martínez-Senra et al., 2013; Fan et al., 2015). The large number of patents generated in recent years in sectors such as biotechnology, electronics, and the energy and environmental sectors, is proof of this (Hall, 2004; Spanos et al., 2014). Seeking methods that develop innovative performance (IP) will always be beneficial, but such inquiry is especially important now, when innovation is recognized as a dynamic capability (Danneels, 2002; Verona and Ravasi, 2003) and a generative source of differentiation (Haavisto, 2014).

Although IP is primarily associated with private firms' R&D activities, R&D activities are also performed in the public sector, specifically in universities (Spanos et al., 2014). One of universities' main objectives is creation of knowledge (Hemmert et al., 2014). University R&D is important because it is one of the main driving forces of the growth process in advanced economies (Meo and Usmani, 2014). R&D activities develop theories and models that explain and predict natural reality (Pavitt, 1998). A sample of their importance may be seen in the average of 213,405.70 documents published in European universities from 1996-2011—primarily in the fields of science and social science—and of 61,504.23 patents in European countries during the same time period (Meo and Usmani, 2014). These facts justify the need to advance IP-related research in universities (Lai and Tsai, 2010).

University R&D groups may be considered one of the main paths for contributing innovative results to the socioeconomic development of regions and countries (Patanakul and Pinto, 2014). The literature proposes that organizations increasingly trust groups as a work tool to overcome current challenges (Lee et al., 2014; Kotlarsky et al., 2015), among them, the need for innovation (Fan et al., 2015). This study focuses on the transactive memory system (TMS) of university R&D groups. The TMS is very useful for work groups because it explains how members of the group each take responsibility for their area of work, contributing their knowledge to the group in general (Cabeza et al., 2013; Kotlarsky et al., 2015), while simultaneously fostering cohesion among its members (Heavey and Simsek, 2015). Such a situation can facilitate IP in R&D groups. To study this relationship, we analyze TMS dimensions of credibility (trust in the reliability of others' knowledge) and coordination (the group's efficacy in identifying the differentiated knowledge of each member) (Lewis, 2003; Fan et al., 2015).

To date, research on TMS has focused on explaining the cognitive processes of groups, the factors that affect these processes, and the results of the group's actions for other processes (Lewis and Herndon, 2011; Kotlarsky et al., 2015). Many studies of the TMS have thus been performed in research laboratories, (Hollingshead, 2001), with samples of students (Lewis, 2004) or teams from a single organization (Austin, 2003). There is, however, an empirical gap in analysis of the relationship between TMS and product IP, notwithstanding the fact that organization of work in groups has been proposed as a crucial factor for developing effective transactive memory (Zajac et al., 2014; Rasmus and Conny, 2015; Kotlarsky et al., 2015) that benefits group processes such as IP (Fan et al., 2015).

While the literature on TMS has analyzed characteristics of the group's members (Zhang et al., 2007; Fan et al., 2015; Hood et al., 2015) and communication processes (Oertel and Antoni, 2015), it has not analyzed teams' characteristics, goals, and work climate (Zhang et al., 2007; Kotlarsky et al., 2015). Our study analyzes variables that describe group behavior that could be related to TMS and IP: trust (TRUST), collective mind (CM), and network ties (NT). Since TMS can enhances the IP process, and the group variables (TRUST, CM and NT) can be considered as cognitive variables that improve the TMS, we propose that TMS can be a bridge between these variables and IP. Thus, the general goal of this study is to analyze how the group variables TRUST, CM, and NT are related to IP, and whether the TMS mediates the relationships of these group variables to IP in university R&D.

This article contributes to the literature in several ways. First, we observe the context of the R&D, attempting to demonstrate that TRUST, CM, and NT are antecedents of TMS. Second, TMS are related to IP as a measure of group performance. Third, we attempt to demonstrate that the TMS is a mediating variable in the relationships described above. Finally, we help to extend the existing literature on work groups and cognitive variables as an alternative for improving the group's work. From the perspective of practice, therefore, managers of R&D groups should attempt to develop TMS in their work groups to obtain better results in IP and thus make greater contributions to society.

The article is structured as follows: After this introduction, we present a literature review to develop the relationship between the variables and study hypotheses. We then present the methodology and data analysis. Finally, we discuss the results and present the main conclusions, limitations, and future lines of research.

Trust, collective mind, and network ties, and TMS

The concept of the TMS was proposed by Wegner et al. (1986) while studying the processes of codifying, storing, and recovering the TMS of intimate couples. The TMS is currently defined as the work cooperation that occurs between members of a group to learn, remember, and communicate relevant knowledge about the group (Hollingshead, 2001; Kotlarsky et al., 2015). In particular, transactive processes refer to communication between people, to the way they codify, store, or recover information (Wegner, 1987; Wegner et al., 1986; Hollingshead, 2001). Use of the TMS is being extended to work groups (Ren and Argote, 2011; Rasmus and Conny, 2015; Kotlarsky et al., 2015) because groups are structures composed of people with complementary abilities committed to a common purpose and sharing a set of goals (Katzenbach and Smith, 2000; Rasmus and Conny, 2015).

The successful functioning of a TMS depends on the formation of many transactive memory structures, that is, on each member of the group connecting to the others' knowledge within the system itself (Wegner et al., 1986). People thus form cognitive representations that, through the knowledge and communication in themselves, enable more effective coordination of tasks and cooperation (Rasmus and Conny, 2015). It is precisely here that TRUST, CM, and NT act. Each of these variables has been explored individually, but the literature has not analyzed their joint connection with TMS (Lewis and Herndon, 2011; Mouzas and Hennenberg, 2015).

TRUST is the belief an individual or group of individuals has in another individual or group (Cumming and Bromiley, 1996). It is based on honest, cooperative actions (Bhattacherjee, 2002). TRUST is considered as a psychological construct, the product of experiencing the interaction of people's values, attitudes, frames of mind, and emotions (Gill et al., 2005; Robertson et al., 2013). It is the reason that researchers in groups characterized by TRUST are more willing to give useful knowledge (Zand, 1972; Huang, 2009) and more receptive to listening to another's knowledge (Mayer et al., 1995)—actions that facilitate credibility and coordination. If there is a relationship of TRUST between group members, all will contribute to success (Uribe et al., 2013), as TRUST facilitates willingness to act according to the criterion of one's colleagues and helps to create affective bonds with the organization or group for which one works (Ferres et al., 2004; Robertson et al., 2013). Trust can thus be an important antecedent for developing the TMS, since it helps to develop credibility and coordination. We therefore propose the following hypothesis:

Hypothesis 1: TRUST is positively related to the TMS in R&D groups.

Weick and Roberts (1993) define CM as a pattern of interrelations attentive to actions in the social system. More recently, Huang (2009) has defined it as the cohesion created by the different interrelations between the members of a group. CM refers to the structures related to the collective meanings that emerge and that are responsible for coordinating the group's activities (Akkerman et al., 2007; Brown, 2015). When group members are aware of the role they play and what they contribute in these interrelations, their activities are more likely to be integrated and coordinated with other members' activities. Members will depend on each other and act as a united group to perform their tasks (Dougherty and Takacs, 2004) and unite their efforts (Huang, 2009), encouraging development of credibility and coordination in the TMS.

When CM develops in a group, its members can undertake actions together. The group is responsible for the tasks, people encourage each other, and actions are integrated as a coherent group to achieve the goal proposed (Huang, 2009; Brown, 2015). CM can thus facilitate the TMS, by helping to develop the collective competences that permit it to overcome obstacles as a group and the desire to remain united until it achieves the goals proposed and to assume the consequences, both positive and negative, as a group (Fernández and Winter, 2003). We therefore propose that:

Hypothesis 2: CM **is positively related to the TMS in R&D groups.**

Organizations increasingly use networked labor (Chen, Rainie, and Wellman, 2012; Lungeanu and Contractor, 2015). Current tendencies in scholarly research reflect the rapid emergence of research that tackles NT (Lungeanu and Contractor, 2015). NT is defined as the real set of all kinds of connections between a set of individuals (Mitchell, 1973). It is strongly related to the frequency of interaction and communication between team members (Chiu et al., 2006). The essential focus of the theory of social capital proposes that the resources residing in the ties created when one works tied into network generate benefits for the members of the network (Nahapiet and Ghoshal, 1998). Yet the literature is still seeking a more dynamic perspective on networks and their constant evolution (Human and Provan, 2000; Hite and Hesterly, 2001). Networks' connection with the TMS can provide such needed analysis. This relationship has important implications for creation of opportunities in groups, as researchers represent a specific type of networked worker (Dimitrova et al., 2013)—workers who collaborate explicitly and exclusively (Lungeanu and Contractor, 2015).

To be tied into a network enables team members to feel comfortable working with each other (Taylor and Greve, 2006; Lungeanu and Contractor, 2015) and fosters development of interpersonal cohesion characterized by the social interaction that arises (Huang, 2009). Further, NT provides privileged information and access to opportunities, and permits people in the network to obtain resources, encouraging credibility and coordination in the TMS (Lee et al., 2014). The TMS provides benefits of integration that are conceptually similar to those described in network theory (Lee et al., 2014). NT enables better use of members' knowledge, which enables them to be more effective in fulfilling creative tasks (Monge and Contractor, 2003; Wu et al., 2009), encouraging the TMS. We thus propose that:

Hypothesis 3: NT is positively related to the TMS in R&D groups.

Relationship between TMS and IP performance

Innovation capability is the capability of an organization to develop and carry out new ideas, such as novelty, experimentation, and creative processes that can lead to new products, services, or technological processes (Fernández et al., 2012). More specifically, product innovation is responsible for satisfying needs by introducing a product on the market (Damanpour and Gopalakrishnan, 2001).

Although much research has demonstrated that TMS have positive effects on the performance of groups and organizations (Hollinghead, 1988; Liang et al., 1995; Morelena and Myaskovski, 2000; Fan et al., 2015), the connection between TMS and IP has received little study. Some theoretical frameworks have emerged, however, that link work groups to innovative performance. Among them we find the interactionist theory of innovation proposed by Woodman et al., (1993), which links group cohesion and communication to innovative performance.

TMS facilitate exchange and diffusion of tacit information through shared memory, helping to promote effective use of human resources and reduce the cognitive development for which each individual is responsible (Akgün et al., 2006). The TMS is responsible for ensuring the availability of important information and for enabling recovery of it. Moreland and Myaskovsky (2000) note that, when members of a group need information but do not remember it, or when they distrust their memory, they can refer to the other team members for help, a climate that encourages product DI. Groups that have developed a TMS can coordinate interactions more effectively (Austin, 2003; Zhang et al., 2007; Fan et al., 2015), developing a key mechanism for IP. Based on the foregoing, we propose the following research hypothesis:

Hypothesis 4: **TMS is positively related to** IP **in R&D groups.**

Mediating role of TMS

Although many studies show that the existence of the TMS is vital for improving the group's performance on all its levels (Ren and Argote, 2011; Kotlarsky et al., 2015), little research has investigated TMS in mediation relationships (e.g., Peltokorpi and Hasu, 2011; Fan et al., 2015). We believe that the TMS may be a perfect mediator in the relationship of TRUST, CM, and NT to IP in R&D groups. First, mediation in the relation between TRUST and IP can be explained because TMS causes the motivations, attitudes, and behavior of the individuals to improve in the context of the team (Lewis and Herndon, 2011; Fan et al., 2015), encouraging product IP. TRUST does not generate a positive result per se. It requires a mechanism that sets this attitude into specific actions. The TMS can thus be seen as an important resource fostering individual and team participation (Kotlarsky et al., 2015) in tasks related to IP (Fan et al., 2015).

On the other hand, the collective thinking that emerges from CM seeks ways to unite all members of a group through the goal of constructing knowledge (Brown, 2015). CM requires members coordinated in work on tasks to believe in the knowledge and work of the other members of the group (credibility), and TMS enables this coordination. The situation described above benefits product IP because, CM leads to that each individual mind works independently of its total capability, while simultaneously contributing with others (Brown, 2015). Because of its characteristics, the TMS can mediate the relationship by permitting the internal attributes of the group's or organization's members to grow through the constant interrelation created between them (Brown and Duguid, 2001; Mouzas and Henneberg, 2015). We know that members of a group are more likely to seek solutions that recombine disconnected ideas—further increasing DI —when they have different abilities, capabilities, and knowledge (TMS) (Guimera et al., 2005; Lungeanu and Contractor, 2015).

Finally, we believe that the TMS has a mediating effect in the relationship between NT and product DI. The characteristics of the TMS allow it to further increase unity of the previously created networks. Generation of innovative ideas requires the capability to recombine (Fleming and Sorenson, 2001) the diverse areas of knowledge the team possesses (West, 2002) and a situation in which the work group's members feel comfortable with each other (Guimera et al., 2005; Taylor and Greve, 2006). Multidisciplinary teams, in which representatives of different domains of knowledge work tied into a network to perform a common task, face challenges related to differentiation and integration of knowledge when working to achieve a common result (Liao et al., 2015; Majchrzak et al., 2012). The TMS's mediation of this relationship can make better use of the members' knowledge and achieve greater coordination. The group can thus be more effective in fulfilling the creative tasks that benefit product IP. We therefore propose:

Hypothesis 5: **TMS mediates the positive relationship between TRUST and product** IP **in R&D groups.**

Hypothesis 6: **TMS mediates the positive relationship between** CM **and product** IP **in R&D groups.**

Hypothesis 7: **TMS mediates the positive relationship between NT and product** IP **in R&D groups.**

Based on the foregoing discussion, Figure 1 illustrates the hypothetical causal relationships in the research model.

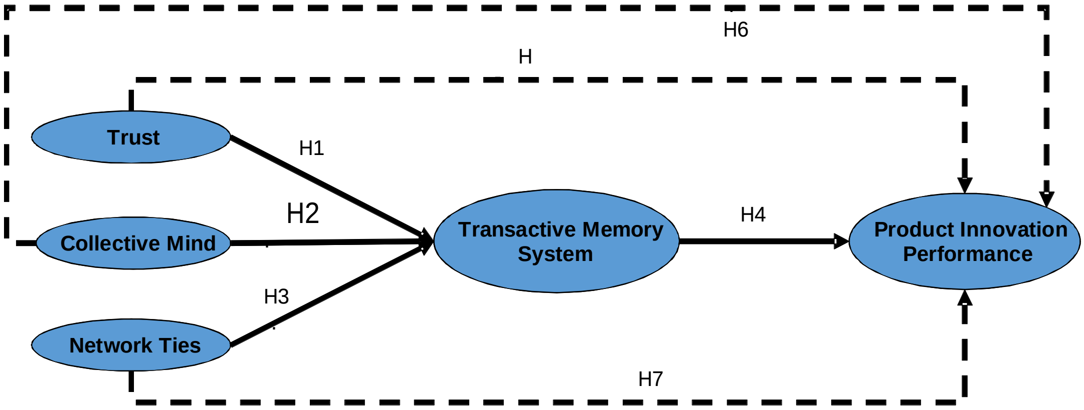

Figure 1. Research model

Research methodology

Sample and data collection

We selected a sample of 3000 university R&D groups through simple random sampling. The groups belong to all areas of knowledge and were chosen independently of their size, region, age of group, or field of knowledge. Choice of a sample of firms located in a single, relatively homogeneous geographic, cultural, legal, and political area minimizes the impact of variables that cannot be controlled in the empirical investigation (Alder, 1983). The data collection procedure consisted of emailing a questionnaire with a cover letter to the director of each group. We obtained 260 questionnaires but rejected three because they were incomplete. 257 questionnaires were finally analyzed, giving a response rate of 8.57%, a sampling error assuming an infinite population of 6.1%, and a confidence level of 95%.

The largest number of surveys in the sample came from R&D groups in the field of humanities. These composed 21% of the sample, followed by economics, social sciences, and law (18%); bio-health sciences (13%); and physics and chemistry, and mathematics and health sciences technology at 11%, respectively. Next were groups from natural resources and ecology (10%), agro-food technologies (7%), computer science and communications (5%), and production technologies (4%).

The groups that composed the sample generally had 5-10 researchers (groups of this size represented 50% of the total sample). 37% of the groups had over 10 researchers, and only 13% had fewer than 5 researchers. Finally, in the period studied, 43.19% of the groups had budgets of 120,000 € devoted to R&D, 19.84% had 60,000€-120,000€, and 36.96% less than 60,000€.

It is important to evaluate how responding early or late to the survey affects or changes the responses given and to what extent this situation influences generalization of the results to the total population. To determine this effect, we measured whether there were significant differences between early and late respondents by analyzing the variance of the variables whose scales could be measured. As we did not find significant differences, we can assume that response time causes no significant bias.

Measurement: scales used

The scales were chosen after an in-depth review of the literature. In each case, we chose the scales that best fit the sector under study. The measurement scale for TRUST is adapted from that proposed by Jarvenpaa and Leidner (1999). This scale fits analysis of TRUST in groups well and has been used to study R&D groups in Taiwan (Huang, 2009). This scale and the others were accompanied by a 7-category Likert scale (1 disagree completely and 7 agree completely).

CM was measured by adapting the scale proposed by Yoo and Kanawattanachai (2001) for two reasons. First, this scale has been used in R&D groups to measure effectiveness; second, the scale has been used to evaluate new product development, and our study specifically analyzes product innovation performance. Finally, NT was measured by adapting the scale proposed by Chiu et al. (2006) to our goals. To analyze TMS, we adapted the scale proposed by Akgün et al. (2005), which prior studies have used specifically to measure the construct in groups. The scale was adapted to achieve better contextualization to the sector studied and the research goals.

Finally, to measure IP, we adapted the scale proposed by Prajogo and Zohal, (2006), which has been previously validated in R&D environments. Table 1 lists each item included in the scales and its descriptive statistics.

Table 1. Scale items and validation

Items	**Mean**	**S.D.**	**Standardized factor loadings (>0.4[a]; t>1.96 [a])**	**Reliability R^2 (>0.5 [a])**	**Composite reliability (>0.7 [b])**	**AVE (>0.5)**	**Cronbach's Alpha (>0.7[b])**
Trust (TR)					.921	.701	.929
The members of my team have great integrity. (TR1)	6.18	1.088	.762	.581			
I can trust the people I work with on my team. (TR2)	6.33	1.001	.893	.797			
The members of my team are highly trustworthy. (TR3)	6.35	.965	.866	.750			
We consider the feelings of each team member. (TR4)	6.16	1.091	Eliminated				
The people on my team are nice. (TR5)	6.36	.917	Eliminated				
There is a spirit of collaboration on my	6.15	1.127	Eliminated				

team. (TR6)							
There is great trust among the people I work with. (TR7)	6.14	1.164	.822	.675			
In my team, we trust each other. (TR8)	6.15	1.105	.839	.704			
Collective mind (CM)					.928	.765	.928
The members of my team have a global perspective that includes outside decisions and the relationships amongst themselves. (CM1)	5.27	1.367	.810	.656			
The members of my team relate research actions carefully amongst themselves. (CM2)	5.13	1.437	.891	.793			
The members of my team make their decisions carefully to maximize the team's total performance. (CM3)	5.10	1.398	.943	.889			
The members of my team have developed a clear understanding of how each research activity should be coordinated. (CM4)	5.16	1.437	.851	.724			
Network ties (NT)					.890	.671	.883
I maintain a close social relationship with some members of my team. (NT1)	5.45	1.603	.883	.780			
I spend a lot of time interacting with some members of the team. (NT2)	5.42	1.509	.763	.582			
I know some members of my team on a personal level. (NT3)	5.93	1.397	.843	.711			
I communicate frequently with some members of the team	6.22	1.065	.781	.611			

(NT4)							
Transactive Memory System (TMS)					.868	.624	.862
I have felt comfortable accepting procedural suggestions from other team members. (TMS1)	6.37	.944	Eliminated				
I trust the knowledge of other members concerning the research. (TMS2)	6.33	.946	Eliminated				
I really trust the information that team members bring to discussion. (TMS3)	6.19	.944	.744	.553			
My team has worked in a collaborative, well-coordinated way. (TMS4)	5.68	1.308	.721	.520			
We manage to perform tasks efficiently and without problems. (TMS5)	5.58	1.147	.822	.675			
There is no confusion about how tasks should be performed. (TMS6)	5.71	1.123	.866	.743			
Product Innovation Performance (PROD)					.892	.625	.889
We are innovative in the group's new research. (PROD1)	5.83	1.209	.753	.567			
We use the latest technological innovations in new research. (PROD2)	5.52	1.358	.802	.644			
Our speed in developing new research is high. (PROD3)	4.97	1.432	.823	.678			
Our group has introduced a high number of new research studies in the market. (PROD4)	4.66	1.729	.799	.639			

A high number of our research studies are pioneering in the scholarly community. (PROD5)	4.82	1.596	.775	.601			

[a] Hulland (1999)
[b] Nunally (1978)

Assessing common method variance

Since the data were obtained through a single-respondent questionnaire, we analyze the possibility of common method variance. First, the scales were pre-tested by experts in the field to eliminate possible errors and confusion (Podsakoff et al., 2012). Second, the presence of common method bias could mean that a single factor explains most of the variance (Podsakoff et al., 2012). To determine whether this is the case, we first observed whether an unrotated factor analysis showed the presence of 4 different factors (Rhee et al., 2010). We then determined whether the results of Harman's one-factor test for model fit with a single factor produced very low values ($\chi 2$/df = 10.257; CFI = 0.571; RMSEA = 0.190; NFI = 0.548; and NNFI =0.523). The results of these tests confirm that there are no problems related to common method variance.

Results

Scale validation

To ensure that we performed valid, reliable analyses, the different measurement scales were subjected to a validation process. First, we studied the scales' one-dimensionality through principal component analysis. The results showed that each of the scales explained a single factor, confirming the scales' one-dimensionality.

Second, we examined the scales' reliability, calculating the Cronbach's alpha for each scale. Table 1 presents the results obtained. As all values exceed the recommended minimum of 0.7 (Nunally, 1978), we can confirm that all of the scales show a good level of reliability. For both this and the previous test, we used SPSS 22.0 software.

Finally, we validated the measurement model using the robust estimation method with EQS 6.1 software. During this validation process, three items in the scale for TRUST and two in the scale for TMS were eliminated because they did not fulfill the minimum standards of reliability. For this test, we examined whether the factor loadings for each item were significant (t-value>1.96, p<0.05) and whether their individual reliability (R^2) exceeded the recommended minimum of 0.5. Table 1 includes the values for each item. The indicators ensure the scales' convergent validity. The fit indices for the measurement model show values above the required minimums (RMSEA=0.063; CFI=0.904; IFI=0.905; NFI=0.828; NNFI=0.890). The minimum recommended values for the RMSEA are below 0.08, the values for the CFI and IFI above 0.9, and the values for the NFI and NNFI above 0.5 (Byrne, 1998; Mulaik et al., 1989).

To complement these tests, we analyzed the scales' composite reliability and average variance extracted (AVE). In these cases, the minimum recommended values are 0.7 and 0.5, respectively (Nunally, 1978). All scales fulfilled both requirements.

Structural model

To analyze the hypotheses, we followed Rhee et al. (2010) in performing decomposition of effects. Decomposition establishes that the total effect of an independent variable on a dependent variable is disaggregated into its indirect and direct effects (Tabachnick and Fidell, 1996; Rhee et al., 2010). The presence of a significant indirect effect indicates that a significant part of the relationship between the dependent and the independent variable is explained through the mediating variable. Figure 2 presents the relationships established between the variables and the results obtained in the structural model, including the direct and indirect effects. We used EQS 6.1 software to perform structural equations modelling (SEM).

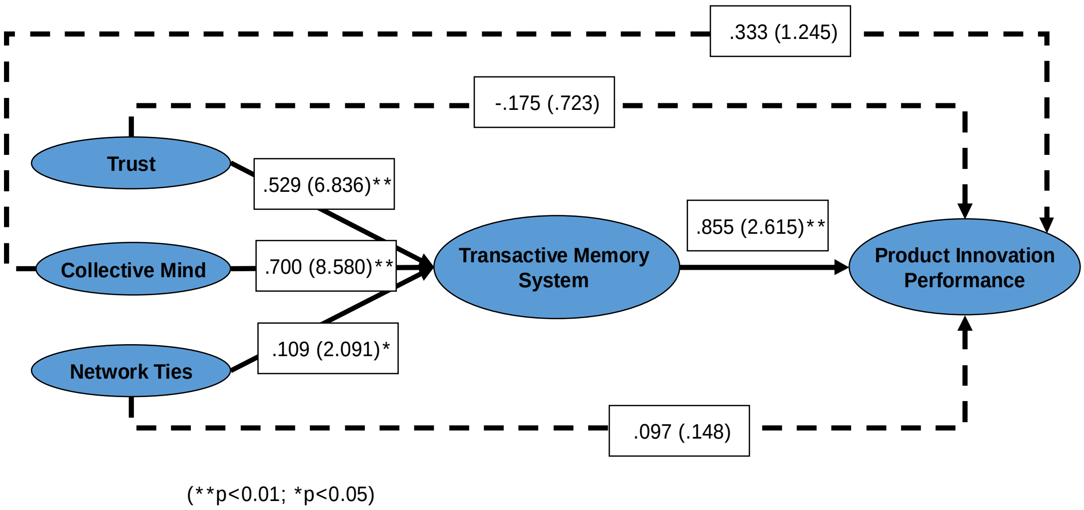

Figure 2. Structural model

Also following Rhee et al. (2010), we estimated an alternate model that included the TMS as exogenous rather than mediating variable. An $\chi 2$ difference test showed significant differences between the two models ($\Delta\chi 2(1)=324.386$, $p=0.00$). Further, the results of the alternate model had less exploratory power (GFI=0.756; AGFI=0.691; NFI=0.796; NNFI=0.804; CFI=0.851; IFI=0.853; RMSEA=0.079), also supporting the decision to include the TMS as mediating variable in the model.

Next, we examined the estimated parameters of the relationships between the variables to contrast the hypotheses. For the variables that act as antecedents of the TMS in the proposed model, the results show a significant and positive relationship between TRUST and the TMS ($\lambda=0.529$, t-value=6.836), between CM and the TMS ($\lambda=0.700$, t-value=8.580), and between NT and the TMS ($\lambda=0.109$, t-value=2.091). These results lead us to accept Hypotheses H1, H2, and H3, respectively.

As to the dependent variable, the results of the structural model show the presence of a positive and significant relationship between the TMS and product IP ($\lambda=0.855$, t-value=2.615). We can thus accept Hypothesis H4.

Finally, to analyze the mediating effect of TMS, we examine the direct relationships of the variables of TRUST, CM and NT to product innovation performance. The results for all relationships (($\lambda=-0.175$, t-value=-0.723; ($\lambda=0.333$, t-value=1.245; ($\lambda=0.097$, t-value=0.148, respectively) show nonsignificant relationships between the variables. These results show that the relationship of TRUST, CM, and NT to product IP occurs through the TMS, which exercises a mediating effect between the variables observed.[4] Hypotheses H5, H6, and H7 are thus supported.

Finally, we analyzed goodness of fit of the structural model fits by examining various indices and their minimum recommended values. We used the goodness of fit index (GFI) = 0.829, adjusted goodness of fit index (AGFI) = 0.778, normed fit index (NFI) = 0.865, non-normed fit index (NNFI) = 0.883, comparative fit index (CFI) = 0.926, Bollen's fit index (IFI) = 0.927, and root mean square error of approximation (RMSEA) = 0.057. All fit indices obtained exceed the required minimum values mentioned above.

In sum, the SEM estimation indicates a model with indicators of acceptable and reliable fit that includes estimations permitting us to accept all hypotheses proposed. The following section discusses the implications of these results.

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[4] To complement this analysis, we used the method proposed by Baron and Kenny (1986) to confirm the existence of mediating effects. All conditions are satisfactorily fulfilled, confirming what the authors call total mediating effect.

Discussion

Contributions

The goal of this study was to determine the relationship between the group variables TRUST, CM and NT, as antecedents of product IP and the mediating effects of the TMS in these relationships. Despite the importance of these variables for group work, only a small number of studies has taken their value into account for IP in work groups. The empirical findings indicate that the three antecedents studied play a considerable role in the creation of a TMS, which positively affects product IP in R&D groups. The most striking result is that the TMS performs a mediating function in the relationship of TRUST, CM, and NT to product IP. Our study thus helps to establish a solid basis for research on groups, the TMS, and IP by contributing new results. These findings are framed and reinforced by the interactionist theory of innovation proposed by Woodman et al. (1993), which links group cohesion and communication to IP. Our results enable us to test this theory and advance it, since they show that a variable of group cohesion such as TMS benefits the group through a mediating effect on IP in groups. Our results indicate that TRUST is positively related to the TMS in R&D, specifically university R&D. TRUST permits university R&D to develop better credibility and coordination within the TMS, which encourages creation of more effective work teams that distribute tasks and responsibilities properly, enabling development of the different roles and domains of knowledge (Brandon and Hollingshead, 2004). Such team integration, created by TRUST, has a positive impact on credibility and coordination within the team (Fan et al., 2015). TRUST in the ability of one's colleagues promotes the active search for information between team members, improving the TMS. Our results thus support studies of team training that indicate that teams whose members learn to resolve a task together develop differentiated knowledge that inheres in the TMS (Oertel and Antoni, 2015). As a result, they obtain a larger quantity of information relevant to the task than teams whose members are trained separately (Moreland and Myaskovsky, 2000). Further, they use the knowledge better to access the competences required at each moment and to coordinate their actions (Sánchez et al., 2006; Oertel and Antoni, 2015).

Next, our results agree with literature that considers CM as an element that signifies cohesion and is important for groups because it creates connections between their members (Huang, 2009; Brown, 2015). Messeni (2011) affirms that the presence of prior connections contributes to increasing exchange in groups. CM also enables development of knowledge incrusted in the group's members. This fact is directed at the way the team members individually coordinate, share, distribute, and recombine amongst themselves (Brown and Duguid, 2001; Brown, 2015). CM thus facilitates the growth of internal attributes of members of the group or organization through the constant interaction created, producing an environment of trust and mutual knowledge. As our results have shown, these circumstances encourage the TMS, as they will develop in an environment previously created previously and sustained in an organizational culture that encourages them.

NT also encourages TMS, because the network members share a series of beliefs and conditions that enable them to believe in and feel secure with the members who are tied into the network. NT enables better communication and favors establishing closer links between individuals and groups. Such a situation nurtures university R&D groups because it enables them not only to integrate but also to access new knowledge (Bih-Huang et al., 2015) and all of the benefits that stem from being tied into a network, thereby encouraging the TMS.

TMS are positively related to performance of product and process IP in university R&D. We know that groups are key mechanisms for improving innovative performance (Gibson and Gibbs, 2006; Fan et al., 2015). Our results provide empirical evidence for prior theoretical studies that connect group processes to innovative performance of the group (Morelena and Myaskovski, 2000; Chen et al., 2013; Fan et al., 2015).

Teamwork and coordination of technical knowledge among the group's members are recognized as important elements for the team's effectiveness (Zhang et al., 2007; Chen et al., 2013). Coordinated teams organize differentiated knowledge effectively, positively influencing

DI (Fan et al., 2015) and enabling increase of competences in new product development (Rothaermel, 2001).

Finally, regarding the mediating effect, TMS is a system that enables the exchange, coordination, and feedback, considering that individual members of the group can serve as an external memory aid for other members of the team. It creates distributed memory in which each member takes care of an area of knowledge, which is coordinated with the other team members to complement and strengthen each other, decreasing the problem of having to know everything. What is important is who specializes in what in order to facilitate knowledge exchange at the group level (Huang and Huang, 2007; Fan et al., 2015). Development of a new product or innovation is recognized as a difficult task (Spanos et al., 2014). With its mediating effect, however, the TMS has the capability to integrate the different functions, activities, and information flows between the members of the group. The mediating effect we have found implies that the TMS leads to greater commitment to increase product IP in groups due to the links created. This result is a significant contribution to the literature, as the mediating role of this variable has never been analyzed in this context. The result may explain why prior studies have not found direct positive relationships between the variables TRUST, NT, or CM and DI.

Implications

First, the results obtained support the conclusion that university R&D uses the perspective of groups in its management process. Further, managers of university R&D in which groups develop TRUST, CM, and NT should stress development of TMS to stimulate IP in their groups and to be more competitive. Universities work with group R&D processes, and such organizations depend increasingly on group structures to facilitate creation of knowledge and innovations. A large part of this research suggests that these group structures are very effective for development of university R&D when they use TMS, since they enable members to focus on their own areas of specialization and use others' experience and knowledge. Our study suggests that group leaders should encourage attitudes that help to develop transactive structures and training in these topics to foster the group variables studied, as well as TMS.

Limitations and future research

Although this study has obtained important results, it has several limitations. First, the transversal nature of the study requires that the results be analyzed with prudence due to the dynamic character of the constructs evaluated. This situation can be corrected by long-term studies that provide more information on the topic. Second, the sample used is composed of R&D groups from nine sectors of knowledge that are not distributed evenly across the sample, possibly affecting the results. The sample is composed only of Spanish R&D groups, a factor that may condition the results due to Spain's particular cultural, political, social, legal, and economic characteristics. Since the perception of each group analyzed represents the criterion of a single director, some results may be affected by subjectivity. This perception may change if midlevel positions and general personnel are interviewed. It would be interesting to study the criteria of research personnel who compose the university R&D groups.

Conclusions

Research on groups, especially in R&D, is growing in the current literature. Many questions remain, however, making this topic a novel one closely interrelated with innovation, knowledge, and psychological variables. The future of organizations is based on proper development of R&D teams.

This investigation presents an empirical study that analyzes the effects of TRUST, CM, and NT, as antecedents of the TMS, while also evaluating the mediating effect of TMS on these relationships with IP. Our results indicate that the facilitating elements TRUST, CM, and NT encourage the creation of the TMS. Further, they show that IP is positively related to development of the TMS. Finally, we demonstrate the mediation of TMS in the relationship of TRUST, CM, and NT to product IP. The study contributes to the analysis of management from a non-entrepreneurial perspective, that of university R&D, and provides empirical information specific to creating a TMS in R&D. As the literature contains no empirical studies that analyze the relationships tested in university R&D environments, it is worth emphasizing that the results enable us to orient these organizations to how to improve their R&D cycle. The investigation serves as a reference for R&D groups concerning group development, as the results provide a work instrument for managers and researchers in university R&D. Further, the results we present provide empirical support for studies of groups and help us to trust increasingly in work groups as another tool to overcome today's challenges.

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SURVIVAL ANALYSIS BASED DECISION SUPPORT SYSTEM – APPLICATION TO PROCESS IMPROVEMENT

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Abstract

Process mining is new science area appeared in the last couple of years for revealing hidden information of log files and for applying it in process development and optimization. Thanks to the quick evolution of this research area and its diversified application, relevant improvements can be observed in several workflow and business models, in which log files have a significant role. We investigate the sequence of sub-processes where the duration and the outcome of the process activities are stochastic so that the process can be successful or failed. In this article, a novel methodology will be presented for applying survival analysis to find the most relevant components which influence the overall behavior of the process. The survival analysis approach is used to determine the right sub-process order. The proposed decision support methodology can be used to support cost reduction projects. An illustrative example related to a testing process shows that with the help of the developed tools we can determine which activities can be shorter or can be eliminated from the overall test sequence.

Keywords: Survival Analysis, Log files, Prediction

Introduction

There is several valuable hidden information in the log files, which would be able to improve an organization's operation and serve the basis of improving business processes. We focus on sequences and we investigate the opportunity of optimization based on the idea that the sequence of diverse process tests can be redesigned, while the characteristic of each one is taken into account. As a result, such an efficient methodology is proposed, by which any process can be improved by any context.

The traditional survival analysis is a statistics method for analyzing the expected duration of time until one or more events happen. It is a widely used method in health care (Collett, 2003; Singh and Mukhopadhyay, 2011; Brenner et al, 2016), cash flow modelling (Ross et al, 2010), bio-statistical analysis (Kleinbaum and Klein, 2005), etc. Wurzenberger et al. (2016) define a model based on log line clustering and Markov chain simulation to create synthetic log data to detect anomalies in computer networks. The presented model requires only a small set of real network data as input to understand the complex real system behaviour. Che et al. (2012) designed a frequent attack sequence based hypergraph clustering algorithm to mine the network security log. The optimized hypergraph clustering algorithm provides a data analysing method for intrusion detecting and active forewarning of the network. Juvonen et al. (2015) propose a framework to find abnormal behaviour from log files. They compared random projection, principal component analysis and diffusion map for anomaly detection. Actual abnormalities were observed from the dataset. Their results are useful when designing next generation of intrusion detection systems.

The new applications of survival analysis are the follows, where further information and steps are applied during the methodology. Improving efficiency of manufacturing processes is also an intensively researched area: Bier Longhi et al. (2015) presented a model to optimize strategies for operation and testing of low-demand safety instrumented systems, applying modelling by fault trees associated with optimization by a genetic algorithm. Torres-Echeverría et al (2009) introduced a new development for modelling the time-dependent probability of failure on demand of parallel architectures, and illustrates its application to multi-objective optimization of proof testing policies for safety instrumented systems. Both papers uses a genetic algorithm with a large number of steps for identifying the optimal solutions. Uryas'ev and Vallerga (1993) proposed a general approach to optimizing the schedules of the standby systems by Markov chains and Fault-tree analysis. Many other papers were published in safety topics, but none of them discuss the process improvement problem in the aspect of event analysis.

The core of the idea is to examine the log file, to formulate general conventions based on typical observations, and to redesign the sequence of the investigated process' steps. However, the ultimate goal is to improve economic operation efficiency, so the definition of the redesigned sequence is in connection on one hand with time, – because it is a requirement to reveal an abnormal event as soon as possible, – on the other hand cost has to be taken into account – since the effectiveness of the method should also be measured. Thus, the process can be qualified and improved to spare time and cost.

In producing environment there are several metrics to evaluate the effectiveness of a system, like KPI, OEE, etc. We shall introduce a novel performance metric in the context of survival analysis, by which the results can be also visualized. Thus, decision making can also be eased by this novel event analysis concept.

This paper introduces a new methodology for optimizing different types of processes using survival analysis. In our work a new application of survival analysis will be presented. The section "Problem definition" shall give a formal and detailed specification about the above-mentioned issue as a preparation for the "Methodology" part of how to use survival analysis in special cases of processes, while the "Case study" illustrates the results of the chosen example, and "Conclusions" summarizes the introduced theme.

Problem definition

In our work the investigated part of the context is the process itself which consists of process steps. Different outcome can be observed on both the process and the set of its steps in a well-defined and arbitrary sequence. However, a log file can be built up out of this information resulting many parameters which describe such a process. The fields of a sample log file with the most important properties can be seen in Table 1.

Table 1 – Most relevant fields in a log file

#	*Entity*	*Event*	*Starting time*	*Finishing time*	*Event Result (success / failed)*

There is usually a row counter line number, which is denoted here by # sign, and it is also indispensable to define an entity which is an abstract denomination, and can be anything representing the subject of the examination. In most case it is also logged what is the event that is observed, in our case it is always a process step. Furthermore, every row can include information about the starting and the finishing time of this event, and of course, whether it is a success or a failed one.

Workflows and business processes can be considered as sequences of activities performed for a given purpose. When the set of the activities is defined as $A = \{a_1, \dots, a_n\}$, a given sequence $s = (s_1, s_2, \dots, s_m)$ is represented as an ordered list, $s_k \in A, k = 1, \dots m$.

The subjects of the activities are referred as *items*, $I = \{i_1, \dots, i_N\}$. The processing of the i_j-th item in the s_k-th activity is denoted by $s_k(i_j)$. The activities are characterized by several properties, like the s_k^R set of required resources and s_k^t duration time.

We assume that in a given sequence s_k should immediately follow s_{k-1}. Hence, the operation of the *k*-th process step is defined by the $(t_{k-1}, t_k]$ time interval, where $t_k = t_{k-1} + s_k^t$. (Please, note that time *t* represents the "age" of the item; *t=0* for every item entering the process).

The processing of an item can generate events, $E = \{e_1, \dots, e_M\}$. We define a dichotomous random variable *Y*, whose $y_{j,l,k}$ values indicate whether the i_j –th item does experience the e_l-th event in the k-th step of the sequence. In our study only one event is defined, so we do not use the index *l*. $y_{j,k} = 1$ shows that the *j*-th item is not successfully processed in the *k*-th activity. In this work we deal with processes where in the case of any fault the whole sequence of processing of the j-th item should be terminated immediately and the probabilities of these faults (and terminations) are independent in every process steps.

Let d_k denote the number of terminations in the k-th process step, $d_k = \sum_{j=1}^{N} y_{j,k}$. If N_k represents the number of items leaving the process, then $N_k = N_{k-1} - d_k$.

The T_k random variable denotes the time when the event occurs. The stochastic nature of the process can be described by survival functions. The elementary survival function represents the probability of that the activity will not be terminated after time t related to the entering of the items, $S_k(t - t_{k-1}) = P(T_k > t - t_{k-1})$. Based on the theory of competing risks, these functions can be independently determined. As N_{k-1} items enter into the k-th process step in this activity, $d_k = N_{k-1}\left(1 - S_k(s_k^t)\right)$ terminations can be expected, and $N_k = N_{k-1}S_k(s_k^t)$ items will leave this step, as at a given time instant $t \in (t_{k-1}, t_k]$ $N_{k-1}\left(1 - S_k\left(t - t_{k-1}\right)\right)$ faults are detected and $N_{k-1}S_k\left(t - t_{k-1}\right)$ items are processed. The introduced terminology can be seen visually on Figure 1.

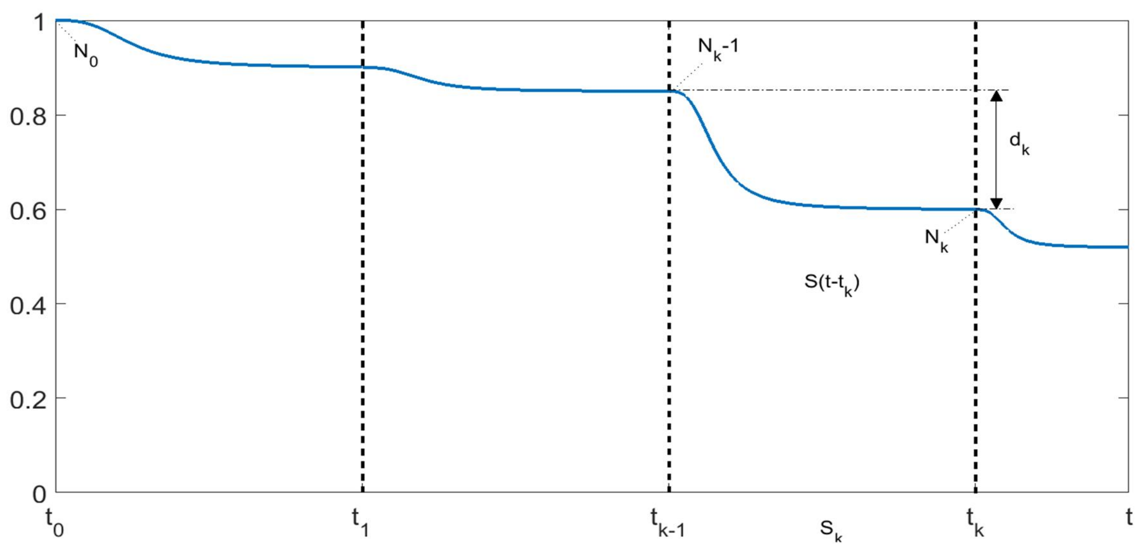

Figure 1 – Pareto Chart considering only the distribution of the failures

The survival function of the whole process can be easily approximated in the $0, t_1, t_2, \dots, t_m$ time instances by the Kaplan-Meier formula. For any time $t \in (t_k, t_{k+1}]$ the probability of surviving is calculated based on the probability of surviving the previous process step multiplied by the conditional probability of surviving past time t_k:

$$S(t) = P(T > t) =$$
$$= P(survive\ in\ [t_{k-1}, t_k)) \times P(survive\ in\ [t_k, t)|survive\ in\ [t_{k-1}, t_k)) \quad (1)$$

The above formula can also be expressed as a product limit if we substitute for the survival probability $S(t_{k-1})$, the product of all fractions that estimate the conditional probabilities for failure times t_{k-1} and earlier. This Kaplan-Meier estimator of the survival functions *S(t)* is piecewise-constant function:

$$S(t) = \prod_{k=1}^{m} \left(1 - \frac{d_k}{N_k}\right) \quad (2)$$

Methodology

The formula based on conditional probability highlights that costs and potential benefits of the process depend on the order of the activities. Our core idea relies on the methodology of the event analysis. Thus, we can reorder the s sequence to reduce the cost of the process, and if it is allowed to vary the s_k^t duration time, we also determine the optimal duration of the processes.

For simplicity, we approximate the processing cost based on the N_{k-1} numbers entering to the process, the $(t_k - t_{k-1})$ processing time and s_k^C cost of processing an item for a unitary time interval:

$$c_k(t) = N_{k-1}s_k^C(t - t_{k-1}) \tag{3}$$

The benefit of processing an item is denoted by s_k^B. The benefit in the actual time instant can be interpreted as the instantaneous potential of detecting a fault. Since this “detection rate” is defined by the hazard function $h_k(t)$,

$$h_k(t) = -\frac{dS_k(t - t_{k-1})/dt}{S_k(t - t_{k-1})} \tag{4}$$

When we define the benefit as $s_k^B h_k(t)$, the B/C ratio can be formulated as

$$\frac{B}{C}(t) = -h_k(t)\frac{s_k^B}{s_k^C N_{k-1}} = -\frac{dS_k(t - t_{k-1})}{dt}\frac{s_k^B}{s_k^C N_{k-1} S_k(t - t_{k-1})} \tag{5}$$

As this equation suggests, in case of test-type processes an activity should be stopped when the derivative of the survival function is becoming small and the sequences should be arranged to have the largest decrease in the survival in the early period of the operations. When the sequence of the activities is optimized, it is beneficial to evaluate the costs and benefits related to the whole time interval (spell) of the operation. The benefit of the test can be calculated as

$$B_k = s_k^B N_{k-1}\left(1 - S_k(t_k - t_{k-1})\right) \tag{6}$$

while the cost is

$$C_k = N_{k-1}s_k^C(t_k - t_{k-1}) \tag{7}$$

The B/C ratio is

$$\frac{B_k}{C_k} = \frac{s_k^B\left(1 - S_k(t_k - t_{k-1})\right)}{s_k^C(t_k - t_{k-1})} = \frac{s_k^B}{s_k^C}\frac{d_k}{(t_k - t_{k-1})} \tag{8}$$

By using this measure it is easy to sort the activities in descendant order and this arrangement can be effectively used to redesign the sequences.

Case study

The presented method is illustrated via the following example in which we examine the test phase of a manufacturing process. The goal is to identify those process steps which fail in most of the cases through the testing phase. In the following straightforward and abstract example the studies of 254.337 tests are considered, and we also know that six process steps are taken into account. Further data is available, 12833 failures are registered over the study interval. The distribution of the failures among the process steps is summarized in Table 2.

Table 2 – The main information about each step

Teststep	**# of failures**	**overall rate**	**sub rate**	**duration (s)**	s_k^C **($)**
Step 1	62	0,02%	0,48%	1000	6

Step 2	1046	0,41%	8,15%	500	3
Step 3	317	0,12%	2,47%	40	0,24
Step 4	3160	1,24%	24,62%	120	0,72
Step 5	368	0,14%	2,87%	10	0,06
Step 6	7880	3,10%	61,40%	400	2,4

Investigating this data, the Pareto-chart of the failures can be visualized, which is shown at Figure 2. If only the number of the failures are considered, the sequence has to be changed according to Table 3.

Table 3 – The sequence based on the distribution of failures

Step 6	Step 4	Step 2	Step 5	Step 3	Step 1

When not only the number of the failures are considered but also the cost of a test step – which comes from the product of a unit cost (0,36 cents per minute) and the mean running time of the step –, another sequence is put out, which is shown at Figure 3.

Table 4 – The sequence based on the distribution of failures and the BC ratio

Step 5	Step 3	Step 6	Step 4	Step 2	Step 1

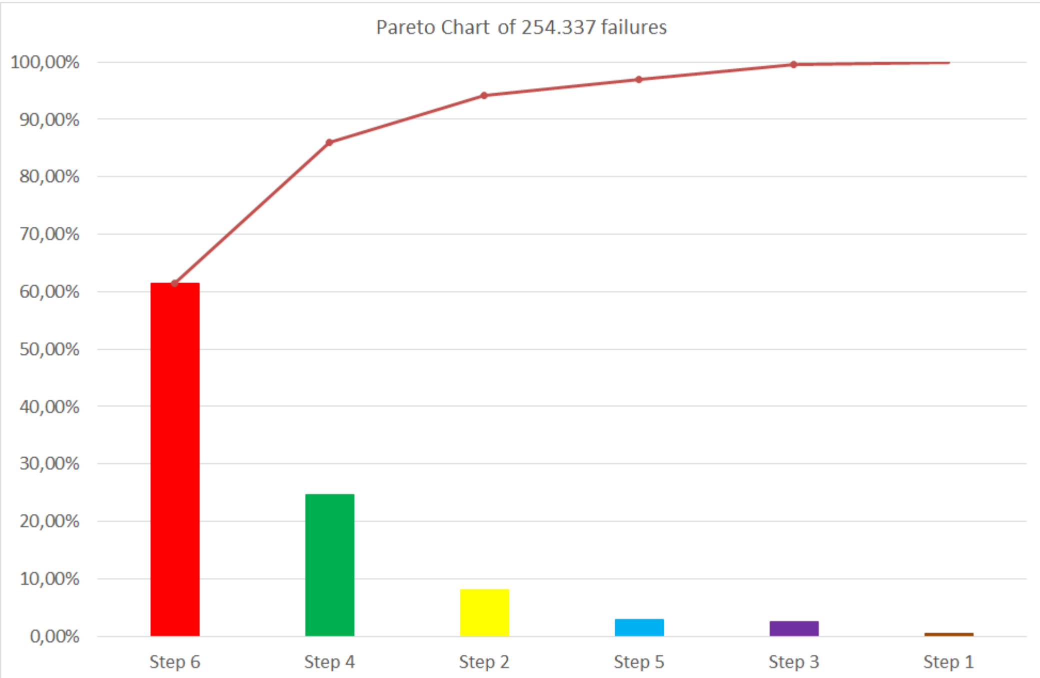

Figure 2 – Pareto Chart considering only the distribution of the failures

The survival function on Figure 4 represents the survivor characteristic of the investigated test example according to the original (continuous line) and the other two sequences (dashed line comes from Figure 2, while dashed-dotted comes from Figure 3).

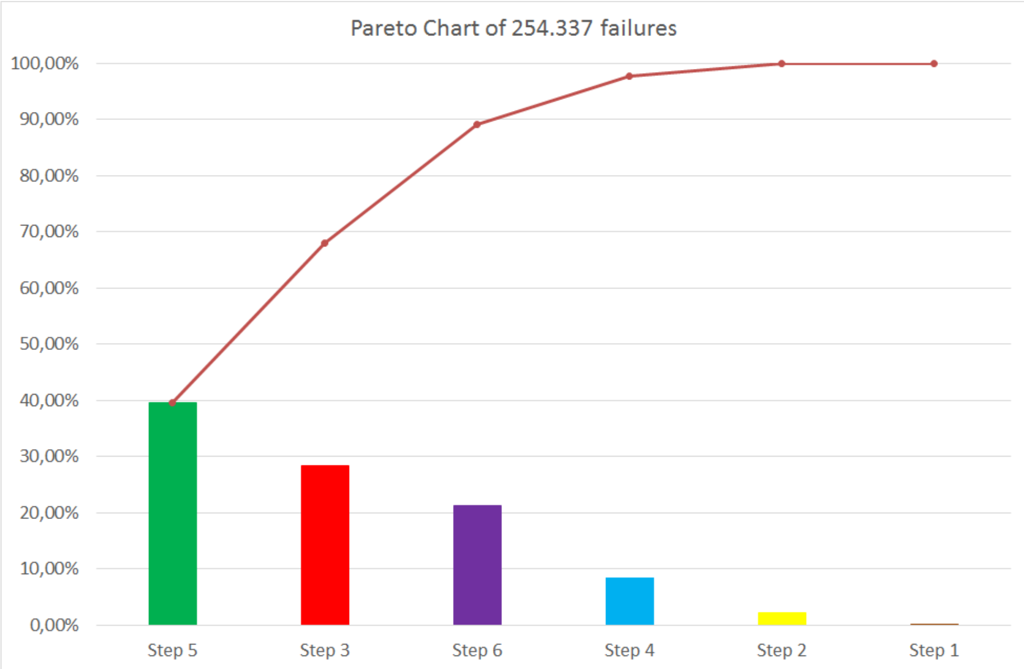

Figure 3 – Pareto Chart considering the distribution of the failures and the cost of a test step

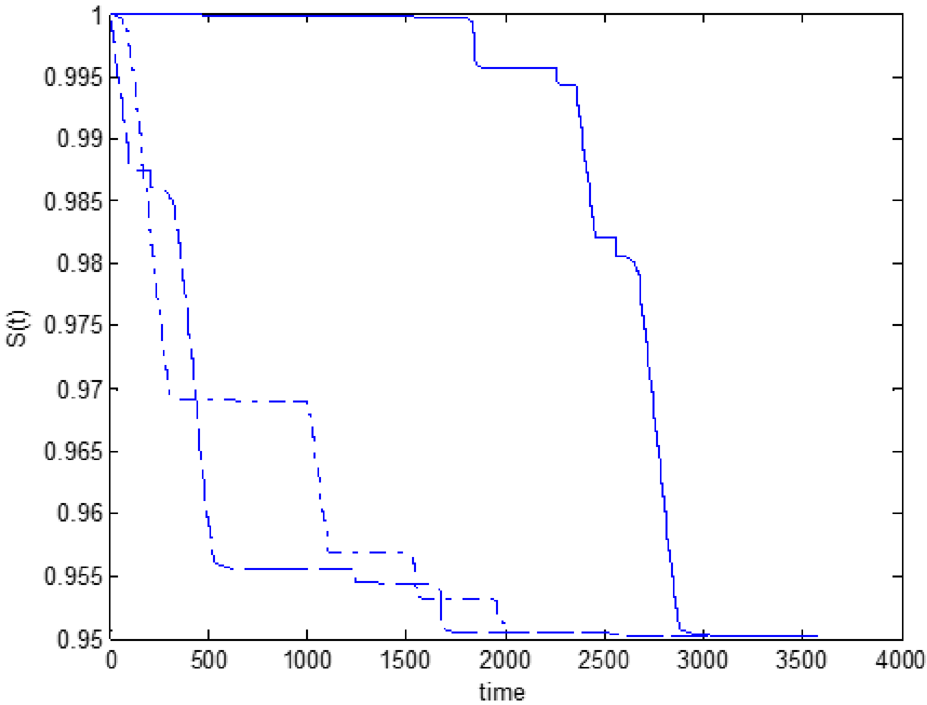

Figure 4 – Survival function of 254.337 tests in the given sequence

It can clearly be seen that if the sequence is modified, we get such a result in which 3% of the entire population dies in the very early phase, contrarily the original sequence more than 2000 seconds are wasted, until such a large amount of failure detection.

The whole process can be further optimized based on the detailed analysis of the individual activities. With the use of eq(5) the unnecessarily long test activities can be shortened.

The two most critical activities were step one and two. We maximized their lengths in 1000 and 2500. It can be seen in Figure 5, while the changes between the first ultimate survival curve and this one is illustrated in Figure 6.

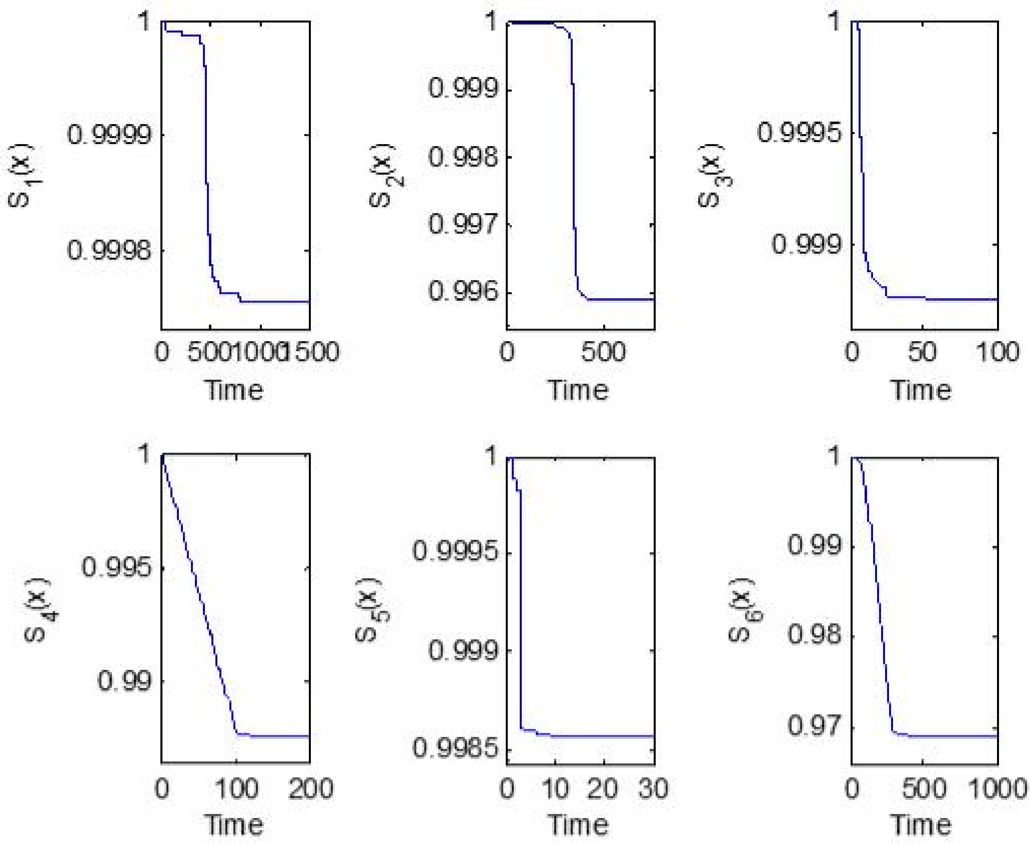

Figure 5 – Detailed analysis of the individual activities

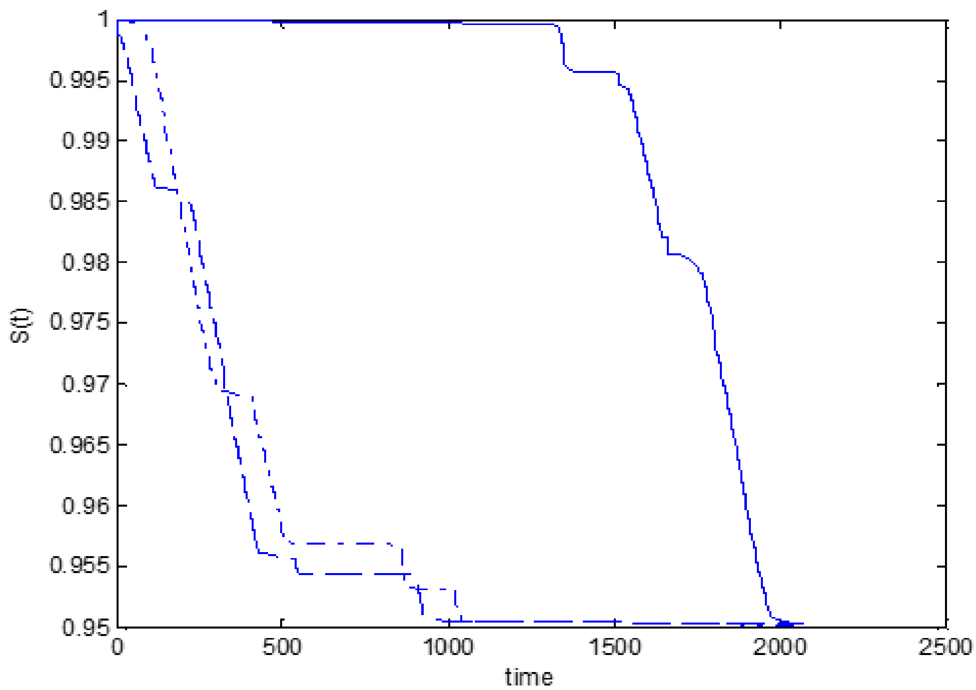

Figure 6 – Survival analysis after detailed sub optimization

Conclusion

We developed a survival analysis based approach for determining optimal order and duration of sequential (test) processes. A cost-benefit analysis based measure is used to evaluate the importance of the activities. The analysis of the individual survival functions can be used to determine the optimal lengths of the process steps. The illustrated example clearly shows the important role of the redesign of test sequences. The proposed survival analysis based decision support methodology opens new perspectives in (test process) improvement in production systems.

Nomenclature

A	–	set of activities
s	–	ordered list
I	–	itemset consisting of process steps
$s_k(i_j)$	–	the i_j-th item in the s_k-th activity
E	–	set of events
Y	–	random variable for the i_j-th item e_l-th event in the k-th step
d_k	–	number of terminations
N_k	–	number of survived processes
T_k	–	random variable for the time when an event occurs
S_t	–	survival function
s_k^C	–	cost of processing an item per unit time
s_k^B	–	benefit of processing an item per unit time
$h_k(t)$	–	hazard function for detection rate
B_K	–	benefit of the test
C_K	–	cost of the test

Acknowledgements

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WATER SOURCE SELECTION FOR A VILLAGE WATER DISTRIBUTION SYSTEM

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Abstract

A water distribution system should have storage (reservoir) so that it is capable for basic domestic purposes, commercial and industrial uses, and to accommodate the flows necessary for emergencies such as firefighting. A service reservoir stores the water and supplies it at the required pressure to the farthest point in the area. In view of the cost of pipelines and uniform pressure distribution, the reservoir should be located near the service area, and a lot of criteria can be considered to accomplish it. That's why selecting an appropriate water source for water distribution systems is a multi-criteria decision making problem (MCDM) to solve. In the paper, concerning the criteria of construction cost, water quality and sustainability, a water source is selected for a village water distribution system by use of fuzzy-mixed TOPSIS method. The proposed method is performed successfully in selecting the best alternative.
Keywords: Water service reservoir, MCDM, fuzzy TOPSIS

Introduction

Water is one of the most essential substances on earth. All human beings, plants and animals need water to survive. Water supply systems are of prime importance in order to provide the water in a sustainable way. A water supply system typically includes: a drainage basin, a raw water collection point, water transfer units (canals or water pipes), water purification facilities, cisterns/tanks or pressure vessels, and pumping stations (https://en.wikipedia.org). Raw water (untreated) is collected from a surface water source (such as an intake on a lake or a river) or from a groundwater source (such as a water well drawing from an underground aquifer) within the watershed that provides the water resource. The raw water is transferred to the water purification facilities using uncovered aqueducts, covered tunnels or underground water pipes. Water treatment occurs before the product reaches the consumer. Treated water is conveyed through a piped network.

A basic component of a water supply system is the service reservoir (tank or tower). A service reservoir stores the treated water and supplies it at the required pressure to the farthest point in the area. Service reservoirs allow fluctuations in demand to be accommodated without a loss of hydraulic integrity. They can also guarantee a supply, at least for part of the day, while the inflow into the network is stopped due to several reasons like maintenance, renovation, contamination incident, etc. The pressure in the water supply system depends upon the water level in the service reservoir. A water supply system needs to guarantee a minimum pressure even at the most remote point in the area. If gravity is insufficient to supply water at an adequate pressure, then pumps are installed to boost the pressure. (Bhardwaj, 2001).

Service reservoirs can be in various forms; for example, towers and tanks (at ground level or underground). Towers provide the extra benefit of increasing pressure head to the downstream network, which is useful in flat regions. In situations where it is not critical to provide extra pressure above that provided by the geography of the land, then ground-level or underground tanks are sufficient. These can be placed on top of hills to use the natural pressure head.

Considering the cost of pipelines and uniform pressure distribution, the reservoir should be located near the center of the service area. In flat areas, it is relatively easy to build the water tower at the center. In hilly areas, however, it may be more advantageous to select the highest point for the construction of an elevated tank, which may lie at one end of the area instead of the center Apart from the center or highest point, the tank or tower can be situated between the residential area and the source of supply, and from the source of supply the water is conveyed to the distribution system by pumping or gravity flow. When the service reservoir lies between the residential area and the source, all the water must pass through the elevated tank before flowing through the area. (Bhardwaj, 2001).

Mountain springs are often utilized as water supply sources in rural areas. In those cases, water from mountain springs can often be transmitted to areas of demand by gravity, limiting the operation and maintenance requirements of a supply system.

Selecting a proper water source and locating its reservoir is a significant problem that requires several criteria to consider. The criteria for water source selection may include quantity, quality, location, cost of development, collection and distribution, and sustainability. In this work, a typical water source selection problem is solved for a village water distribution network system where the service reservoir (tank) is to be located between the residential area and the source of supply.

Literature Review

Most of the researches in the literature were concerned with the design of water storage tank sizes (Upshaw et al., 2013; Akbar et al., 2014; Stanton and Javadi, 2014; Marchi et al., 2016). A complete literature review on optimal tank design in water distribution networks was given by Batchabani and Fuamba (2014). On the other hand, Kurek and Ostfeld (2013) worked on system design (water quality, pumps, operation and storage sizing) of water distribution systems. Unlike those studies, a typical site selection problem for water banking in unconfined aquifers through artificial recharge was carried out by Bhuiyan (2015). To our knowledge, there are no studies in the literature on water storage site selection as was defined in this paper. This finding makes this work original and exemplary.

The Problem

Yapraklı is a village of Çankırı city located at the north-central region of Turkey and has a population around 2000 living in about 400 houses. The houses are fairly close to one another, not scattered broadly over the landscape, and are mostly of two-storied. Further, almost one-third of the houses have small gardens (around 100m2), and the villagers are mostly engaged in agriculture and animal husbandry. Cattle and sheep are fed in half of the houses. The daily water demand of the village in hot season is about 600m3 while it is 250m3 for out of hot season (personal, animal and agricultural water needs are included) (http://kisi.deu.edu.tr, http://cevre.bilkent.edu.tr). Although many patterns of village life exist, the village is one of the big ones and the houses are situated together for sociability and defense, and land surrounding the living area is farmed. The villagers have experienced water shortage problems causing serious difficulties in their lives. That's why a need for having a sustainable water infrastructure has emerged. Considering the future water need of Yapraklı, a project was initiated under the leadership of village administration committee in order to select and site the new water sources and construct service reservoirs to support the current water distribution network.

Since Yapraklı is located in a hilly area, it would be advantageous to select the highest point for the construction of the service reservoir. However, due to the water supply restriction, there is another alternative location at the lowest part of the area, where a pumping station is needed in order to provide water to the network.

A service reservoir (over ground, concrete, 3 m average depth, inlet and outlet flow of water equipment, 600 m3 capacity) was needed in order to provide permanent and uninterrupted water supply to the residents of the village. The village is surrounded by hills north and west, and an irrigation dam lies in between these hills. The problem is to select a location for service reservoir that will supply water to the distribution network of the village. Because of its geographical location, it is possible to provide water from natural resources in the hills as well as directly from the irrigation dam. Regarding the capacity of its natural water springs and the water availability from the dam, different alternative solutions are possible to consider in line with the water demand of the village. The following alternatives are generated for water source location problem (Figure 1).

Alternative A: Construct the reservoir on the north side of the village and feed it with natural spring water. New pipeline and spring supply basin construction is necessary. It provides water of high quality through natural flow of water. Pipeline distance is 2.4 km. Risk of water shortage (due to drought and technical reasons) is considerable.

Alternative B: Construct the reservoir on the north side of the village and feed it with water supplied from the dam. New pipeline and pumping station is necessary. It provides water of poor quality through pumping system. Distance to pumping station (dam) is 1.1 km. Risk of water shortage (due to drought and technical reasons) is quite low.

Alternative C: Construct the reservoir on the west side of the village and feed it mainly with natural spring water (80 %) and partially with dam water (20 % - during hot season). New pipeline and spring supply basin construction is necessary. It provides water of medium quality through natural flow of water and pumping system. Pipeline distance to the spring is 8 km, and to the dam it is 0.9 km. New pipeline and spring supply basin construction are necessary. The water is provided through both natural flow of water and pumping system. Risk of water shortage (due to drought and technical reasons) is low.

The Data

All the monetary and nonmonetary data necessary for the analysis are collected to evaluate the alternatives and are used for selecting the best one. As all the alternatives are projected for the same type of service reservoirs, and the plumbing connections from the reservoirs to the water distribution network are almost the same, reservoir construction and connection costs are ignored. Project duration is assumed to be 20 years for alternative evaluations. Village population (water demand) is assumed to be constant for the project duration. Though water treatment is needed at varying levels in both reservoirs before feeding the network, its cost is of negligible amount.

The necessary data is given below in Table 1.

Table 1. Data for alternative sources

Selection Criteria	**Alternative A**	**Alternative B**	**Alternative C**
Investment cost (pipeline + pump station)[12]	1900/20 = 95	760/20 = 38	1640/20 = 82
Operation and maintenance cost[1]	3	47	8
Total cost/year	*98*	*85*	*90*
Water quality (over 100)	100	60	80
Sustainability (over 100)	93	98	95

[1]Monetary values are in thousand Turkish Liras. [2]Investment cost is transformed to yearly basis.

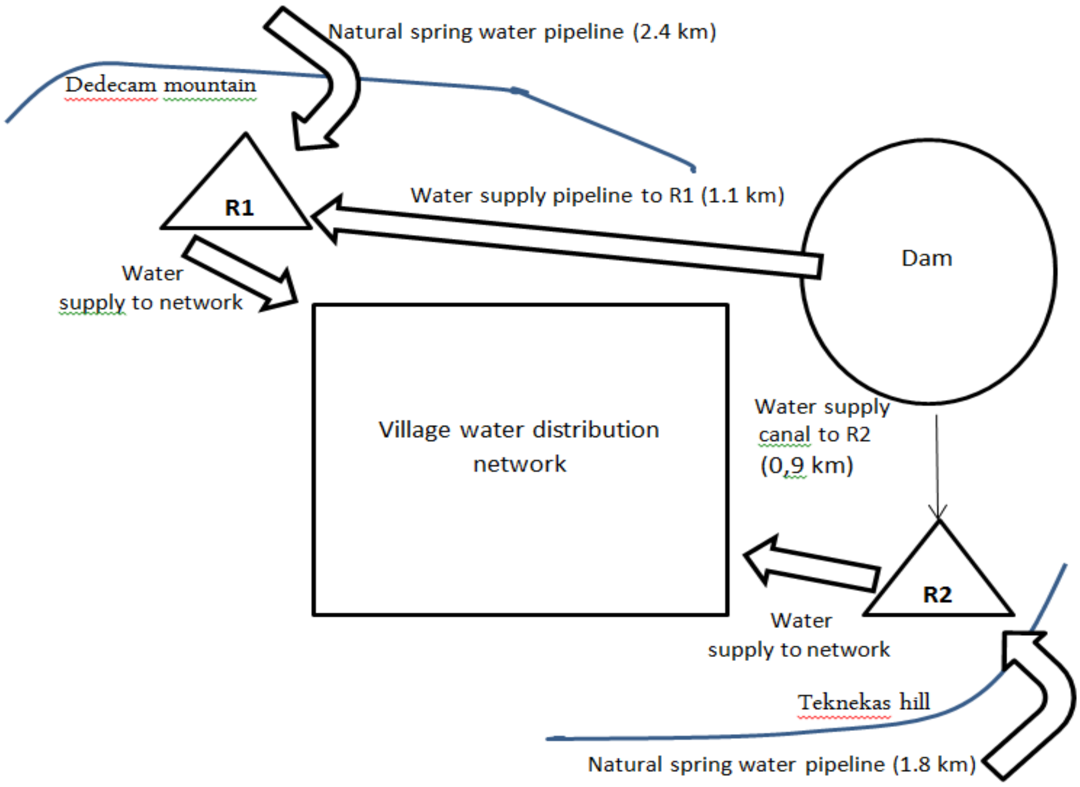

Figure 1- Locational illustration of the village water supply and distribution system

The Method

Fuzzy-mixed multiple-criteria decision making (MCDM) method TOPSIS is used to solve the problem. TOPSIS (Technique for order performance by similarity to ideal solution) is one of the known classical MCDM method, was first developed by Hwang and Yoon (1981) for solving a MCDM problem. It bases upon the concept that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS). In the process of TOPSIS, the performance ratings and the weights of the criteria are given as crisp values.

Under many conditions, crisp data are inadequate to model real-life situations. Since human judgements including preferences are often vague and cannot estimate his preference with an exact numerical value, a more realistic approach may be to use linguistic assessments instead of numerical values, that is, to suppose that the ratings and weights of the criteria in the problem are assessed by means of linguistic variables (Zadeh, 1975). In general, multi-criteria problems adhere to uncertain and imprecise data, and fuzzy set theory is adequate to deal with it. That’s why we have chosen fuzzy-mixed TOPSIS method to apply in our case. During the analysis, monetary values are taken as crisp numbers while other values (nonmonetary-subjective evaluations) are expressed as fuzzy numbers.

In the study, application of the method is realized as follows. First, linguistic variables are used to assess the weights of all criteria and the ratings of each alternative with respect to each criterion. Then, we convert the decision matrix into a triangular fuzzy decision matrix and construct a weighted normalized fuzzy decision matrix once the DMs’ fuzzy ratings have been pooled. According to the concept of TOPSIS, we define the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS). And then, the distance between triangular fuzzy ratings (numbers) are found by vertex method (Dong and Shah, 1987). Furthermore, using the vertex method, we calculate the distance of each alternative from FPIS and FNIS, respectively. Finally, a closeness coefficient (CC) of each alternative is defined to determine the ranking order of all alternatives. The higher value of CC indicates that an alternative is closer to FPIS and farther from FNIS simultaneously. The method provides a ranking of the alternatives in quantitative terms so that it will be possible to compare them with each other and find the most appropriate one. (For a detailed study of fuzzy TOPSIS method, see Chen, 2000)

Application

The problem structure is illustrated in Fig 2.

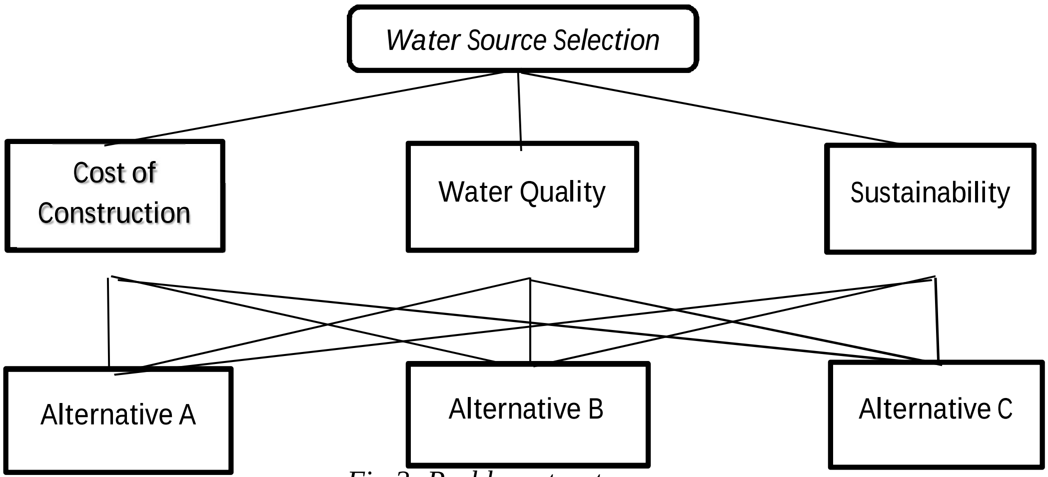

Fig 2- Problem structure

Linguistic expressions were used in weighting the criteria and ranking the alternatives. The expressions and the corresponding triangular fuzzy numbers are given in Table 2 and Table 3.

Table 2- Linguistic expressions and their corresponding triangular fuzzy numbers used in weighting of criteria

Expressions	**T. Fuzzy Numbers**	**Expressions**	**T. Fuzzy Numbers**
Very low	0, 0, 0.1	Medium high	0.5, 0.7, 0.9
Low	0, 0.1, 0.3	High	0.7, 0.9, 1.0
Medium low	0.1, 0.3, 0.5	Very high	0.9, 1.0, 1.0
Medium	0.3, 0.5, 0.7		

Source: Chen, C. T. (2000), "Extensions of the TOPSIS for group decision-making under fuzzy environment", *Fuzzy Sets and Systems*, Vol. 114, No. 1, pp. 5.

Table 3- Linguistic expressions and their corresponding triangular fuzzy numbers used in ranking of alternatives

Expressions	**T. Fuzzy Numbers**	**Expressions**	**T. Fuzzy Numbers**
Very poor	0, 0, 1	Medium good	5, 7, 9
Poor	0, 1, 3	Good	7, 9, 10
Medium poor	1, 3, 5	Very good	9, 10, 10
Fair	3, 5, 7		

Source: Chen, C. T. (2000), "Extensions of the TOPSIS for group decision-making under fuzzy environment", *Fuzzy Sets and Systems*, Vol. 114, No. 1, pp. 5.

In order to get preferences about nonmonetary criteria, an expert committee of three people (village mayor, state water works representative, civil engineer) was established. The committee members were named as decision makers (DMs) in the study, and they expressed their views about the criteria and the alternatives as linguistic. Based on the above tables, DMs' fuzzy evaluation of the criteria (weights of the criteria), and fuzzy evaluation of the alternatives with respect to the criteria, are given in Table 4 and Table 5.

Table 4- DMs' fuzzy evaluation of the criteria (weights of the criteria)

Criteria	DM1	DM2	DM2	Average
C1	0.9, 1.0, 1.0	0.9, 1.0, 1.0	0.7, 0.9, 1.0	0.83, 0.97, 1.0
C2	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.43, 0.63, 0.83
C3	0.7, 0.9, 1.0	0.7, 0.9, 1.0	0.9, 1.0, 1.0	0.77, 0.93, 1.0

Table 5- DMs' fuzzy evaluation of the alternatives with respect to the criteria

Criteria	Alternatives	DM1	DM2	DM3	Average
C1	AA	98	98	98	98
	AB	85	85	85	85
	AC	90	90	90	90
C2	AA	9, 10, 10	9, 10, 10	9, 10, 10	9, 10, 10
	AB	5, 7, 9	3, 5, 7	1, 3, 5	3, 5, 7
	AC	7, 9, 10	5, 7, 9	5, 7, 9	5.7, 7.7, 9.3
C3	AA	3, 5, 7	5, 7, 9	3, 5, 7	3.7, 5.7, 7.7
	AB	7, 9, 10	9, 10, 10	5, 7, 9	7, 8.7, 9.7
	AC	5, 7, 9	5, 7, 9	7, 9, 10	5.7, 7.7, 8.7

The linear scale transformation is used here to transform the various criteria scales into a comparable scale. Benefit and cost criteria are handled in different ways (maximization and minimization). Normalized and weighted normalized fuzzy evaluation of alternatives are given in Table 6 and Table 7.

Table 6- DMs' normalized fuzzy evaluation of the alternatives with respect to the criteria

Criteria	Alternatives	Normalized Numbers
C1	AA	0.87
	AB	1.0
	AC	0.94
C2	AA	0.9, 1.0, 1.0
	AB	0.3, 0.5, 0.7
	AC	0.57, 0.77, 0.93
C3	AA	0.38, 0.59, 0.79
	AB	0.72, 0.90, 1.0
	AC	0.59, 0.79, 0.90

Table 7- Weighted fuzzy evaluation of the alternatives with respect to the criteria

Criteria	AA	AB	AC
C1	0.72, 0.84, 0.87	0.83, 0.97, 1.0	0.78, 0.91, 0.94
C2	0.39, 0.63, 0.83	0.13, 0.32, 0.58	0.25, 0.49, 0.77
C3	0.29, 0.55, 0.79	0.55, 0.84, 1.0	0.45, 0.73, 0.90

The shortest distance from the positive ideal solution (D^+) and the farthest from the negative ideal solution (D^-), and the CCs are given in Table 8. The alternatives are ranked in the same table as well.

Table 8- D^+, D^-, CC values and the ranking of alternatives

Alternatives	D^+	D^-	CC	Rank
AA	1.1322	2.0130	0.6400	3
AB	0.8395	2.1442	0.7186	1
AC	1.0401	2.1435	0.6733	2

Results

When we look at Table 8, we see that the best alternative is the second one (AB) with its highest CC figure of 0.7186. Alternative C takes the second row with its CC figure of 0.6733, and the third alternative (AC) has the minimum CC value of 0.6400 and stands in the last row. In other words, when cost of construction, water quality and sustainability are concerned, the best solution for the water source is to construct the reservoir on the north side of the village and feed it with water supplied from the dam. Table 4 indicates that the most important criterion in selecting the alternative is the construction cost, secondly sustainability, and thirdly water quality. When Table 1 is viewed, it is apparent that the alternative AB has the minimum cost and the highest sustainability figures, which enable it to be selected as the first one among others.

Conclusion

Each water distribution system should have storage facility (reservoir) capable to meet the water needs of domestic, commercial and industrial consumers, and to accommodate the flows necessary for emergencies as well. Basically, water reservoirs are aimed to provide continuous flow of water under uniform pressure. Many criteria are taken into account for this purpose and these facilities must be properly constructed.

Sometimes, we need to decide among several options. This study revealed simple but scientific and realistic application of such a problem. Although TOPSS is widely known method of MCDM, using crisp and fuzzy values at the same time and implementing it in a real case has been a novelty. This study could be carried out in greater detail, however, it would not be appropriate to complicate the situation with the data not important enough.

Several assumptions were made in order to make the case simple such that, as all the alternatives are projected for the same type of service reservoirs, and the plumbing connections from the reservoirs to the water distribution network are almost the same, reservoir construction and connection costs were ignored. Project duration was assumed to be 20 years for alternative evaluations. Village population (water demand) was assumed to be constant for the project duration. Though water treatment is needed at varying levels in both reservoirs before feeding the network, its cost was of negligible amount.

The method was applied successfully and the most appropriate option was determined. Nevertheless, this method can be adopted for further studies that have more evident data, and can be extended to even storage capacity selection, geographical positioning, reservoir typing and construction applications in terms of various alterations.

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SUSTAINABLE PURCHASING: THE INFLUENCE ON RISK PRACTICES ON THE TRIPLE BOTTOM LINE

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Abstract

This paper presents research findings from an international study of purchasing strategy, practices and performance with a focus on sustainability. Current research into sustainable supply chains is lacking a focus on the triple bottom line of environmental, social and economic performance and few studies have examined the role of risk in achieving these objectives. This research provides evidence that companies can provide sustainability benefits without compromising economic sustainability, and that the integration of risk practices can improve performance overall.
Keywords: Sustainability, supply chains, risk management, triple bottom line

Introduction

The purpose of this paper is to show how sustainability priorities impact purchasing practices on sustainability and risk, and consequently, triple-bottom-line (TBL) outcomes. Literature has reinforced the view that sustainability actions are in place in part due to related risks from the supply base (Cousin et al., 2004) and that a focus on risk management may improve sustainability-related performance (Hofman et al., 2014). Research has examined the drivers of sustainable purchasing (Carter and Jennings, 2004; Walker et al. 2008). However less research has focused on purchasing practices and even less demonstrated the role of risk management practices at the purchasing level across the three dimensions of supply chain sustainability. Research shows that these sustainability dimensions are treated differently, for example environmental purchasing focusing on reducing the supply base impacts through improved products or processes (Blome et al., 2014), whereas social issues (supplier child labor or worker conditions) may be seen as avoidance of non-compliance (Marshall et al., 2015). Supply chain risk management is seen as "*the ability of a firm to understand and manage its economic, environmental, and social risks in the supply chain*" (Carter and Rogers, 2008 p.366). Supply chain risk practices typically comprise risk assessment and management dimensions which can lead to improved supply chain performance (Zsidisin & Wagner, 2010; Wieland and Wallenburg, 2012).

This research seeks to address the following research questions. First, do supply chain sustainability strategy and practices impact the triple bottom line? Second, are risk management practices driven by supply chain sustainability strategy and do these practices impact the triple bottom line? From this we hypothesize that sustainability priorities drive investments in purchasing practices related to environmental, social and risk management. In turn we suggest a link between these practices and sustainability performance on the supply side as well as cost and operational performance. This research proposes a conceptual model that considers the relationship between sustainability strategy priorities with environmental, social and risk-based purchasing practices and ultimately their influence on TBL objectives at the purchasing level.

Sustainable Purchasing, Risk and the TBL

Sustainable Purchasing: strategies, practices and performance

Sustainable purchasing has started to become an important topic in the area of operations and supply chain management. A number of recent review papers have helped summarize current research knowledge in this topic and have provided definitions. Miemczyk et al. (2012 p. 489) defined sustainable purchasing as "*the consideration of environmental, social, ethical and economic issues in the management of the organization's external resources in such a way that the supply of all goods, services, capabilities and knowledge that are necessary for running, maintaining and managing the organization's primary and support activities provide value not only to the organization but also to society and the economy.*" An important element of this definition is that sustainable purchasing takes into account environmental, social and economic issues. Addressing these various outcomes is typically known as the TBL. Broadly, sustainable purchasing can be considered as the intention to buy products and services that are more sustainable. Hence this means the selection, the assessment and development of suppliers in a manner that enhances sustainability of the buying firm. In general the importance of sustainability to the firm and its constituent functions impacts on the investment in sustainability related supply chain practices (Carter and Jennings, 2004; Carter and Rogers, 2008; Zhu et al., 2007). Having a sustainable or corporate responsible purchasing is driven by a number of factors which have been well developed in past research (Carter and Jennings, 2004; Salam, 2009; Zhu and Sarkis, 2007). However the majority of research has focused on environmental/social sustainability in the supply chain (Carter and Carter, 1998; Hokey and Galle, 2001; Zsidisin and Siferd, 2001), or environmental/green and social combined together (Luzzini et al., 2015), and therefore less is known about whether both environmental and social sustainability foci have effects on the levels of investment in both environmental and social practices. Hence we offer the following hypothesis:

H1: Higher emphasis on environmental and social priorities in purchasing has a positive effect on environmental and social supply chain practices

Although companies may have the intention to buy more sustainably, achieving more sustainable outcomes requires the investment in specific practices (Carter and Rogers, 2008). These practices may differ according to the results desired and an under investment may lead to targets not being met. Therefore the explanation of sustainable performance through purchasing needs to take into account the practices put in place. Most research looking at sustainable supply practices has concentrated on green or environmental outcomes relating buying products which are greener and avoid hazardous materials within these products which can cause harm or damage especially when disposed of (Lee, 2015; Rauer and Kaufmann, 2015; Tachizawa and Wong, 2015; Wong et al., 2015). On the social side companies need to be aware of the way their suppliers treat their employees and may ask suppliers to agree to codes of conduct and carry out audits to ensure that they comply with these standards (Marshall et al., 2015; Sancha et al., 2015; Shafiq et al., 2014).

Research has looked at the impact of sustainable purchasing on performance and broadly found a positive link between the investment in sustainable purchasing and numerous outcomes which include sustainability metrics as well as other types of outcomes such as operational performance (Carter and Easton, 2011). However the majority of research has focused on environmental/green sustainability issues rather than social issues. In general a positive link has been found between environmental/green purchasing and performance, although with some mixed results (Vachon and Klassen, 2006, 2008; Zhu and Sarkis, 2004). In fact examining how these different supply chain sustainability actions affect performance is still rare in extant research (Seuring and Muller, 2008) despite the apparent need to address multiple aspects of sustainability (Varsei et al., 2014). One of the first attempts to examine the effects of sustainable purchasing on the different elements of sustainability (green, social and economic) found a positive link between sustainable supplier cooperation and green and social behaviours (Hollos et al., 2012). However the link between practices focusing on green or social sustainability and performance is not so clear (Hollos et al., 2012). Building on previous studies, we expect the following:

H2: Increased use of environmental and social supply chain practices has a positive effect on TBL performance

Sustainable Purchasing and Risk

Research on sustainability related risks in purchasing and supply management is a relatively neglected area (Hofmann et al., 2014). This is rather surprising given the frequently cited anecdotal evidence of supply risks related to environmental or social non-compliance (Hajmohammad and Vachon, 2015). Supply risks in general have been identified as important for firm performance overall (Ritchie and Brindley, 2007; Zsidisin et al., 2000). The first phases in risk management namely identification and assessment (Zsidisin et al 2004) are key to PSMs role in protecting the firm from negative impacts (Jüttner, 2005). Research has shown that risk assessment practices should go alongside other supply management practices such as selection and assessment in order to reduce risks and their impacts such as supply disruptions (Craighead et al., 2007).

Examining the role of risk practices by purchasing functions and the impact on sustainability and triple bottom line is relatively new in supply chain management research. Foerstl et al. (2010) suggest that the integration of risk assessment into sustainable supply practices can lead to enhanced performance outcomes related to both reputational effects and operational performance, by enabling risk mitigation strategies where they will be most effective (the selection and development of suppliers related to sustainability). Building on this other researchers have found that supply risk damage to the focal firm can occur due to disruptions but especially from stakeholder reactions when considering sustainability risk sources (Hofmann et al., 2014). Others also point out the importance of sustainability related supply risks stating that depending on the level of risk and dependence, supply managers may adopt monitoring or collaborative approaches with suppliers (Hajmohammad and Vachon, 2015).

Despite these contributions there still exists a lack of evidence on the impact of combining sustainability practices and risk assessment on the different aspects of sustainability and on supply management performance in general. Hence we develop two hypotheses to test the link between the importance of sustainable purchasing on risk assessment practices and the impact of these practices on the triple bottom line performance. From previous research we expect that a focus on both environmental and social sustainability is positively linked to investment in supply chain risk assessment practice and offer the following hypothesis:

H3: Higher emphasis on environmental and social priorities in purchasing is positively related to increased supply chain risk assessment practices.

Given that risk assessment can help focus supplier practices such as assessment and development on the right suppliers and the right issues, optimizing the use of environmental and social supply chain practices, we expect the use of risk assessment practices to have a positive influence on triple bottom line performance. Thus we state the following hypothesis:

H4: Increased use of supply chain risk assessment practices has a positive effect on TBL performance

These hypotheses can be summarized in the following path model testing the influence of purchasing sustainable priorities, sustainable and risk assessment practices and TBL performance.

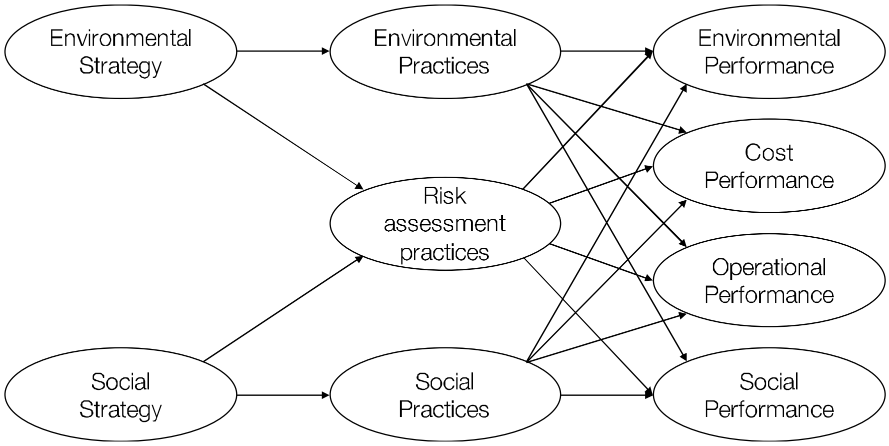


Figure 1 – Conceptual model

Methodology

Survey development and data collection

The hypotheses were tested using data collected in the second half of 2014 through a through the second wave of the International Purchasing Survey (IPS2), involving supply management researchers in four European countries (Finland, Germany, Italy, and Ireland). The research project utilised an online survey questionnaire about purchasing/SC priorities, practices, and performance using constructs derived from the literature. Since both the survey design and data collection involved multiple countries, a common methodological toolkit was developed in order to provide guidance to partner institutions throughout the project duration. The survey was developed in English starting from the main theoretical frameworks that inspired the study. Given the diverse interests of each research partner in terms of research topics, a method team selected a few grand theories after a review of the most important and promising theories in purchasing and supply management literature, including agency theory. All the constructs investigated through the survey have been organised into a construct book, reporting the construct name and typology, definitions, survey items, scales, underlying theory, and corresponding references. A particular aspect of the survey is that it benefits from the adoption of a category-level perspective. In fact, strategies are never truly implemented until they are integrated at the category or product family level (Handfield et al., 2005), and these different categories often adopt different managerial approaches (Gelderman and Van Weele, 2005).

The English version of the questionnaire was translated into different languages using the TRAPD (Translation, Review, Adjudication, Pre-testing, and Documentation) procedure (Harkness et al., 2004) and subsequently tested by submitting it to a couple of purchasing executives in each country to check the clarity of the questions. Before and during the pre-testing phase, special emphasis was placed on the quality of the question formulation in order to reduce potential bias resulting from respondents' misleading cognition (Poggie, 1972; Schwarz and Oyserman, 2001). We concentrated our questions on observable data to exclude every possible scope of interpretation. The final version of the survey tool was uploaded onto the project website and made visible only to respondents selected in the sampling procedure. The

Internet survey offers higher levels of accuracy and reduces missing values due to either the respondent or some data entry mistakes (Boyer et al., 2002).

In each country, firms were randomly sampled from a national, publicly available database. Sampling criteria were pre-agreed among the participating researchers: only firms with more than 50 employees from the manufacturing (ISIC codes from 10 to 33) and professional service firms (ISIC codes from 62 to 66, and from 69 to 75) were included in the sample. Next, each country worked to recover contacts of key informants at the sampled firms. The paper authors were in charge of the data collection in Italy.

Respondents were firstly contacted over the phone to determine their availability to give answers and to provide guidance for the survey completion. A script for the telephone call with respondents was provided within the method toolkit as well as a draft text of subsequent e-mails. After a respondent agreed to participate, he or she was contacted via a customised e-mail including the survey link. Reminder e-mails and telephone calls were made to those who had not responded. Following similar key-informant-based research studies (Cini et al., 1993; Cousins, 2005), the goal was to find the right person within the organisation who was able to respond to all the questions about the purchasing/SC strategy, the buyer–supplier relation, purchasing practices, and performance. For this reason, mostly CPOs, VPs of Purchasing/SC, Purchasing/SC Directors, and Purchasing/SC Managers were involved. The respondents consisted of highly qualified purchasing/SC professionals who had played important roles in the purchasing functions of their firms.

The databases across all four countries included a total of 20,515 companies that fit our sampling criteria. Of these, 3,068 were selected through random sampling, and out of these 3,059 were contacted (some companies were noticed after sampling to not fit the criteria, e.g. the company moved abroad, was no longer in the industry specified, or no longer fit the criterion for at least 50 people). Out of these, 1,059 were contacted via phone (for those not reached, either a suitable respondent was never located in the company or the suitable respondent never answered our calls, despite multiple attempts). A total of 656 companies agreed to participate, and out of these, 305 useable responses were received. Thus, the response rate considering companies that received the link for the questionnaire was relatively high at 46%. Considering all the companies reached, the resulting response rate was 28.8%.

After the data collection process, each country cleaned its own data in accordance with a common agreement and conducted tests regarding non-response bias. Non-respondent bias was tested by ruling out the differences in terms of size and sector distributions between respondents and non-respondents (Scott and Overton, 1997).

Given that we relied on a single respondent design, we controlled for common method bias in two ways: through the design of the study and through statistical control (Podsakoff et al., 2003). Regarding the survey, the research project was labelled as a broad overview of purchasing/SC management: no explicit reference to the intention to test antecedents of supplier performance was evident. Thus, the respondents' attention was not drawn to the relationships being targeted in this study. Questions including items and constructs related to each other in the general model were also separated in the questionnaire in order to prevent respondents from developing their own theories about possible cause–effect relationships. Furthermore, the questionnaire was carefully created and pre-tested and respondents were assured of strict confidentiality. Finally, we used different scales and formats for the independent and criterion measures (Podsakoff et al., 2003). As a second mean to ensure against common method bias, we examined the unrotated factor solution for the constructs included in our model (Podsakoff and Organ, 1986), checking that neither a single nor a general factor was likely to account for the majority of the covariance among the measures.

Table 1 – Sample descriptive statistics

Descriptive	Freq.	%	Descriptive	Freq.	%
Country			***Industry Sector***		
Italy	99	32.5	Manufacturing	234	76.7
Germany	70	23	Information and comm.	23	7.6
Finland	84	27.5	Finance and insurance	19	6.2
Ireland	52	17	Professional, scientific, and technical activities	29	9.5
Purchasing categories			***Respondent position***		
Raw materials	125	41	Purchasing director	53	17.4
Components and supplies	90	29.5	Purchasing manager	153	50.2
IT services	28	9.2	Senior, Project buyer	34	11.1
Logistics services	16	5.2	Buyer, Purchasing agent	28	9.2
Office equipment and supplies	19	6.2	Other	32	10.5
Maintenance and cleaning	27	8.9	Missing	5	1.6
Employees					
Medium (50–249)	150	49.1			
Large (250–1000)	78	25.6			
Very large (> 1000)	75	24.6			
Missing	2	0.7			
Total	**305**	**100**		**305**	**100**

Measures

The operationalisation of the constructs was based on existing measures. All the items used to measure the latent variables we target are shown in Table 2.

The buyer's strategic purchasing competitive priorities and the supplier's performance were assessed following the production competence framework adopted by Gonzalez-Benito (2007). Respondents were asked – on the one hand – to what extent the purchasing management has emphasized the priorities over the past 2 years on a Likert-like scale from 1 ("Not at all") to 6 ("To a great extent"). On the other hand, respondents were asked to what extent the supplier's performance has met management's expectations from 1 ("Far below expectations") to 6 ("Far above expectations"). The emphasis on environmental and social sustainability practices was mainly measured following Hofer et al. (2012), with some items added from ElTayeb et al. (2010) and Pagell and Wu (2009). Respondents were asked on a Likert-like scale ranging from 1 ("Totally disagree") to 6 ("Totally agree") to what extent they agree or disagree on a series of statements regarding both environmental and social practices. Finally, risk assessment was adapted from Wieland and Wallenburg (2012). Respondents were asked which measure are taken in order to counter unexpected disruptions of the material or service flow on a Likert-like scale from 1 ("Totally disagree") to 6 ("Totally agree").

Findings

Hypotheses were tested using structural equation modelling (SEM) with the maximum likelihood (ML) estimation method. Most SEM applications described in the literature are analysed with this methodology. The hypothesised model was tested statistically in a simultaneous analysis of the entire system of variables to determine the extent to which it was consistent with the data. Where goodness-of-fit is adequate, the model can be seen as a plausible explanation of postulated interactions between constructs. The research model is analysed and interpreted sequentially: first the assessment of the reliability and validity of the measurement model and secondly the assessment of the structural model (Hulland et al., 1996). The R software (https://cran.r-project.org) was used to estimate both the measurement model and the structural model. The ML algorithm was used to obtain the paths, the loadings, the weights, and the quality criteria.

Measurement model

The measurement model consists of ten multi-item constructs with a total of 38 indicators. We used several tests to determine the convergent and discriminant validity of the six reflective constructs. We controlled through an exploratory factor analysis that all item loadings between an indicator and its posited underlying latent variable were greater than 0.7 — with no relevant cross-loadings.

Next, Table 2 shows the measurement scales of the reflective constructs investigated by our research model through confirmatory factor analysis (CFA). We verified the measures by assessing reliability and unidimensionality of each of the nine constructs, i.e. item-to-total correlations within each construct were examined (Churchill, 1979). Our measurement model is able to provide to a great extent discriminant validity as well as convergent validity (Bagozzi & Yi, 1988; Anderson & Gerbing, 1988; Fornell & Larcker, 1981): both composite reliability (CR) and average variance extracted (AVE) were above the recommended threshold of 0.7 and 0.5, respectively (Fornell and Larcker, 1981; Nunnally and Burstein, 1994). Only the cost performance AVE is slightly below the threshold, none of the constructs violates the Fornell-Larcker criterion. To further test for discriminant validity, we compared the squared correlation between two latent constructs and their AVE estimates (Fornell and Larcker, 1981). These constructs meet the validity condition of the AVE estimates exceeding the squared correlation between each pair of constructs (see Table 3).

Finally, we can evaluate the overall model fit in two ways (Hu & Bentler, 1998): with the chi-square goodness-of-fit statistic and with other absolute or relative fit indices. It is quite common in management literature to avoid using the chi-square p-value as this measure is particularly sensitive to sample size and assumptions of normality (Hu & Bentler, 1998). As a consequence other fit indices are preferred to the p-value. Some authors suggest to check for the ratio between chi-square value and degrees of freedom in the model, where cutoffs values ranges from <2 to <5 depending on the investigator (e.g., Byrne, 1989; Kelloway, 1998). Another way to evaluate the fit of a model is to use fit indices that have been offered to supplement the chi-square. Fit indices range from 0 to 1, with values closer to 1 indicating good fit. Hu and Bentler (1999) recommend MLE-based fit indices and also suggest a two-index presentation strategy with, among others, the comparative fit index (CFI), and Gamma hat or root mean square error of approximation (RMSEA). The CFA reveals a sufficient model fit attested through such fit indices for the measurement model (Bollen, 1989; Shah & Goldstein, 2006): χ^2=870.9; χ^2/d.f.=1.46; RMSEA=.045; CFI=.961. Following the recommendations of Bagozzi and Yi (1988) as well as Bagozzi and Baumgartner (1994) the quality of our model can be judged as sufficient.

Structural model

The postulated path model produced a sufficient fit to the data (χ^2 = 1020.6; χ^2/d.f. = 1.64; RMSEA = .053; CFI =.943). Figure 2 shows the results of the hypotheses testing.

According to Hypothesis 1 higher emphasis on environmental and social priorities has a positive effect on environmental and social practices. Indeed we find a significant and positive relationship between the orientation of the purchasing sustainability strategy and the related practices. This indicates that there are specific practices for either environmental or social priorities which include both monitoring elements as well as collaborative actions including training and development on both sets of issues.

Hypothesis 2 states that an increased use of environmental and social practices has a positive effect on TBL performance. However we only find significant links between the practices and their corresponding environmental or social performance. Social practices are shown to be positively related to environmental performance but not vice versa. This may be explained considering that social standards (such as the Global Compact), also include environmental criteria whereas environmental standards tend to be more specific and issue related. Unlike other research we find no link between environmental or social practices and operational or cost performance.

Our third hypothesis states that higher environmental and social priorities are positively related to increased risk assessment practices. Contrary to other suggested links between the importance of sustainable purchasing and risk assessment practices, our study finds that only a focus on social priorities leads to increased risk assessment of the supply base. This may be explained through social issues being more inherently risk based, i.e. where companies are focusing on supplier compliance to various labour related issues such as working time agreements, minimum wage and age requirements. Conversely while there is an element of compliance in environmental issues there is also opportunity to improve performance through greater recycling levels or energy efficiency which go beyond compliance risks. Also environmental issues may be more advanced or mature and so the basic risks of non-compliance have already been dealt with.

Our final hypothesis states that the increased use of risk assessment practices has a positive effect on TBL performance. This hypothesis is entirely supported in our study showing positive effects not only on social performance, as might be expected from the previous hypothesis, but that risk assessment in general also has positive results for environmental, operational and cost performance.

Table 2 – CFA results

First-order construct	Indicator	Loading	Mean	Std dev.	CR	AVE
Environmental strategy	Supplier ability to meet agreed environmental performance goals	0.8956	3.71	1.37	0.882	0.717
	Ensuring that purchased products or services contain green attributes	0.9363				
	Ensuring that purchased products or services do not contain environmentally undesirable substance	0.6871				
Social strategy	Enforcement of a code of conduct for suppliers	0.8390	3.16	1.47	0.865	0.683
	Independent audits of ethical performance of suppliers	0.8194				
	More stringent ethical and social mandates than required in host countries	0.8202				
Environmental practices	Major suppliers are selected using criteria that include environmental dimensions	0.8627	3.04	1.36	0.905	0.618
	Major suppliers are required to adhere to certain environmental standards	0.8584				
	We audit major suppliers on environmental dimensions.	0.8180				
	Purchased products and services are being designed to meet environmental objectives.	0.8330				
	Major suppliers are involved in environmental research and development.	0.6910				
	We provide environmental training and information to major suppliers.	0.6209				
Social practices	Major suppliers are selected using criteria that include ethical and/or social dimensions	0.8790	2.92	1.44	0.924	0.674
	Major suppliers are required to adhere to certain ethical and/or social standards	0.8863				
	We audit suppliers on ethical and/or social dimensions	0.8045				
	We provide training and information to major suppliers on ethics/social responsibility	0.6384				
	Major suppliers' processes are required to meet ethical and social objectives	0.9139				
	Major suppliers are involved in stakeholder dialogue and / or engagement in ethical or social issues	0.7707				
Risk assessment practices	Systematic identification of sources for such disruptions	0.7131	3.83	1.21	0.902	0.700
	Assessment of both our own risks and risks of major suppliers	0.8679				
	Assigned individuals responsible for the management of such risks	0.8145				
	Continuous monitoring of developments that might promote such disruptions	0.9359				
Environmental	Supplier ability to meet agreed environmental performance goals	0.9079	3.93	0.95	0.879	0.714

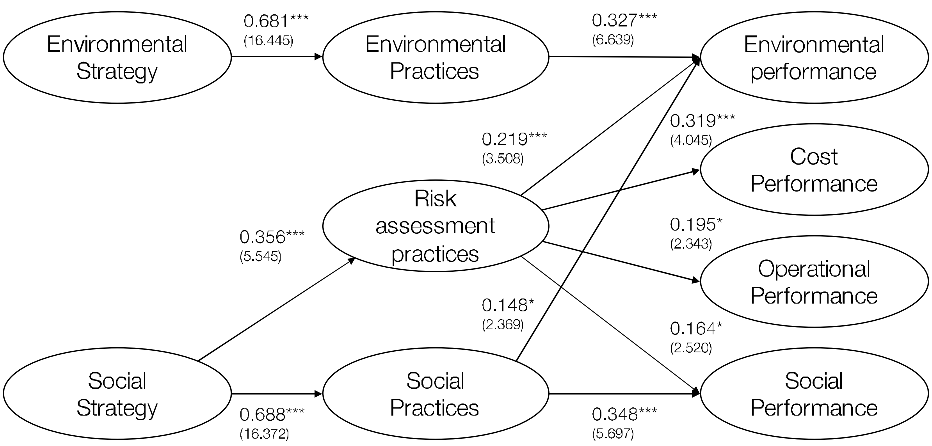
performance	Ensuring that purchased products/services contain green attributes	0.9567				
	Ensuring that purchased products/services do not contain environmentally undesirable substance	0.6338				
Social performance	Enforcement of a code of conduct for suppliers	0.8532	3.70	1.07	0.934	0.825
	Independent audits of ethical performance of suppliers	0.9103				
	More stringent ethical and social mandates than required in host countries	0.9588				
Cost performance	Labour productivity in the purchasing department	0.6389	4.29	0.86	0.701	0.438
	Productivity of purchasing resources	0.6594				
	Low cost of purchases (e.g. purchasing price, transportation)	0.6874				
Quality performance	Features and functionality of purchased products or services	0.6304	4.31	0.69	0.866	0.622
	Durability of purchased products or services	0.8931				
	Reliability of purchased products or services	0.8720				
	Fit between purchasing specifications and purchased products or services	0.7301				
Delivery performance	Short internal order processing times	0.7063	4.06	0.85	0.773	0.531
	Short delivery times by suppliers	0.7153				
	Fulfilment of agreed schedules by suppliers	0.7639				

Fit indexes: *chi-square=870.9; p-value=0.000; chi/d.f.=1.46; CFI=.961; RMSEA=.045*

Table 3 – Correlation Matrix

Variables	1	2	3	4	5	6	7	8	9	10
1. Environmental strategy	**0.847**									
2. Environmental practices	0.661	**0.786**								
3. Social strategy	0.759	0.551	**0.826**							
4. Social practices	0.460	0.722	0.688	**0.821**						
5. Risk management practices	0.280	0.347	0.339	0.270	**0.834**					
6. Environmental performance	0.370	0.548	0.303	0.451	0.348	**0.845**				
7. Social performance	0.230	0.367	0.370	0.416	0.252	0.756	**0.908**			
8. Cost performance	0.185	0.223	0.223	0.225	0.307	0.449	0.344	**0.662**		
9. Quality performance	0.185	0.124	0.183	0.104	0.128	0.330	0.272	0.581	**0.789**	
10. Delivery performance	0.316	0.258	0.266	0.293	0.146	0.347	0.228	0.800	0.544	**0.729**

The square root of the average variance extracted (AVE) is shown in bold on the diagonal. Correlations are in the lower triangle of the matrix.



***p-value<0.001; **p-value<0.01; *p-value<0.05; the value of the test statistic is in brackets

Fit indexes: *chi-square=1020.6; p-value=0.0000; chi/d.f.=1.64; CFI=0.943; RMSEA=.053*

Figure 2 – SEM results

Discussion

In general our study supports the link between a focus on sustainable supply chain management, the investment in practices and the positive impact on sustainability-related performance. However we do not find support for investment in environmental and social supply chain practices having a positive effect on operational and cost performance, rather that the effect is neutral, at least at the purchasing category level. Thus this research supports other findings that companies that focus on sustainability in their supply chain will invest more in environmental and social supply chain practices (Carter and Jennings, 2004), the effect on performance are limited to their corresponding actions. While previous research found positive links between green practices and cost and operational performance, but not no links with social practices (Hollos et al., 2012), we found no operational or cost performance benefits from investing in these practices. This may be explained by the way that the purchasing function measures operational and cost performance benefits, focusing on short term target and effects. Both environmental and social improvements, although supported in our study, may only have long term impacts on performance due to the longer return on investment for green technologies or longer term effects on reputational gains from improved social compliance.

The impact of a sustainable supply chain priority on risk assessment is supported but only from a social sustainability point of view. This is the first time that the link between these two constructs have been tested. Interestingly it seems that social issues are the main driver for risk assessment in the context of sustainability actions. As suggested in the findings, social issues may have more of a compliance related orientation and may been relatively new for companies and therefore the main focus is on identifying where the worst problems are. Importantly it seems from our research that an investment in risk assessment practices has a significant impact on sustainability, cost and operational performance measures, unlike sustainability practices on their own. Therefore we may suppose that for sustainability actions to have a significant impact on the triple bottom line they must be combined with risk assessment actions that continuously identify and monitor where problems might occur.

Conclusions and contribution

Our first contribution is that indeed there are differences between the influence of social, environmental, risk-based practices and performance outcomes depending on which type of sustainability outcome is targeted. Both, environmental and social priorities relate to investment in sustainability practices which turn relate to improved sustainability performance. However, neither environmental nor social practices influence cost and operational performance – supporting a ‘neutral’ role of these practices from a purchasing function perspective. In a sense this is a positive sign that companies have moved beyond sustainability being a significant cost of operating and that both environmental and social performance can be improved without compromising on costs or other performance dimensions.

Our second contribution reveals that social priorities appear to support risk-based practices, but that environmental priorities have no influence. This supports widely publicized examples of companies continuing to fail on social sustainability and the current challenge of purchasing firms to reduce risk-based social problems. Therefore companies that identify a need to address social issues in their supply chains will invest more in risk assessment activities. This finding is important because while normative studies suggest a link between social issues and the need to invest in risk-based approaches, very few empirical studies have demonstrated they are related.

Our third contribution is that while environmental and social supply chain practices have a neutral role in operational and cost performance, risk assessment practices do have a positive effect on the triple bottom line. This is also an important contribution to the field because this research suggests that while the investment in environmental and social practices is neutral with regard to cost and operational performance, the additional investment in risk assessment can perhaps help focus these activities that also optimizes the full triple bottom line.

Future research could explore these issue further by understanding the links between sustainability practices and risk practices and specific risk outcomes related to supply chain disruptions and reputational damage related to sustainability issues. There are a number of limitation to this study which would need to be addressed in future studies. In particular the risk profiles of the specific categories might provide further insights into how the investment in practices can influence performance. Also more detailed studies might reveal the specific ways that sustainability and risk management practices interact. Like all cross-sectional empirical studies the causal links between practice and performance remains to be tested, perhaps through longitudinal studies, which could also include longer term performance indicators such as reputational benefits. Finally, this study focuses on single respondent, purchasing managers, and therefore it would be prudent for future studies to consider whether outcomes at the supplier level are consistent with buyer perceptions.

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THE INSTITUTIONAL DETERMINANTS OF CORPORATE SOCIAL RESPONSIBILITY: THE FSQCA APPROACH

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Abstract
Despite a growing body of literature, the influence of institution-level antecedents on corporate social responsibility (CSR) has received limited attention. To fill this gap, this paper explores the effect of institutional configurations on a firm's CSR engagement. Specifically, we test for the complementary and substitution effects among national culture and formal institutions. The fuzzy-set qualitative comparative analysis (fsQCA) confirms that institutional configurations affect firm CSR engagement. Furthermore, this paper shows that national culture complements formal institutions in motivating firms to pursue superior CSR performance, whereas formal institutions substitutes national culture in forcing firms to meet average CSR performance.
Keywords: Corporate social responsibility (CSR), Institutional theory, Fuzzy-set qualitative comparative analysis (fsQCA)

"We cannot solve problems by using the same kind of thinking we used when we created them."

Albert Einstein

Introduction

Give that corporate social responsibility (CSR) already includes the aspect of society in its label, one would think that institutional theory would be a core conceptual lens in understanding the social responsibility of business all along. However, the previous literature on CSR neglects the societal aspects (Brammer, Jackson, & Matten, 2012). In spite of extensive research on firm CSR engagement and its link with firm-level determinants (e.g., McWilliams & Siegel, 2001; Surroca, Tribó, & Waddock, 2010) and financial consequences (e.g., Margolis, Elfenbein, & Walsh, 2007; Orlitzky, Schmidt, & Rynes, 2003), few studies investigate the institutional antecedents of firm CSR engagement (Jackson & Apostolakou, 2010).

Institutional theory posits that formal and informal institutions create a variety of coercive, normative, or mimetic pressures on firms to adopt particular structures or practices to enhance their legitimacy (DiMaggio & Powell, 1991). Recently, several conceptual studies seek to understand how institutional differences across countries may influence firm CSR engagement (Aguilera, Williams, Conley, & Rupp, 2006; Campbell, 2007; Matten & Moon, 2008). Although a handful of empirical studies explore the institutional antecedents of CSR, most of them unilaterally put the focus on the impacts of formal institutions (e.g. Chih, Chih, & Chen, 2010; Ioannou & Serafeim, 2012) or the impacts on informal institutions (e.g. Ho, Wang, & Vitell, 2012; Lenssen et al., 2007). Since formal and informal institutions work hand in hand to impose systematic pressure and/or incentives on firm's behavior (e.g. Brammer et al., 2012; Gjølberg, 2009), researchers should consider incorporating both types of institutions in the model simultaneously. According to the literature review, no study explores the interaction effects among informal and formal institutions (i.e. the effect of institutional configurations) on firm CSR engagement.

This study attempts to fill this gap by exploring how institutional configurations affect firm CSR engagement. Specifically, we explore the complementary and substitution effects among national culture and formal institutions through analyzing thirty-two countries from S&P Global 1200 index. Given the research purpose to explore the institutional configurations and the small sample size, we choose to apply fuzzy-set qualitative comparative analysis (fsQCA), which has several advantages over multiple regression analysis (MRA) (Ragin, 2000; Woodside, 2013). This method allows researchers to observe substitution and complementarity among institutions by testing for combined effects of causal factors with asymmetric data (Fiss, 2007). Pioneering research proves the effectiveness of using fsQCA to explore the impact of institutional factors on CSR (Gjølberg, 2009).

The results from fsQCA confirm that a specific institutional configuration shapes the environment firms are facing, which further influences the extent of firms' CSR engagement. Moreover, this study finds that formal and informal institutions work together to impose systematic pressure on firm CSR engagement. Compared to formal institutions, cultural values tend to be better at motivating firms to voluntarily go beyond legal requirements and thus increase their likelihood to be CSR leaders, while formal institutions tend to be better at forcing firms to meet minimum legal requirements thus increases their likelihood to be average CSR performers. Overall, the impacts of institutions as a system are more relevant to average CSR performers rather than CSR leaders. This study contributes to a more contextually grounded framework for analyzing CSR engagement and offers important theoretical and managerial implications for both future research and the policy making regarding CSR.

In the next section, we review relevant literature. The third section describes the database and the methodology. The fourth and fifth sections report the empirical findings and discussion respectively. Last, we provide the concluding remarks and directions for future studies.

Literature review

Despite a growing body of research on CSR, no widely accepted definition of CSR exists (Jackson & Apostolakou, 2010). While common definitions of CSR include mandatory responsibilities such as legal compliance, or societal expectations (Carroll, 1999), a recurring theme in CSR debate is its grounding in the voluntary behavior of companies (Brammer et al., 2012). A universal definition of CSR is inherently problematic in light of institutional differences (Matten & Moon, 2008). The historical and political nature of institutions suggests that a universally valid definition of CSR is not desirable (Brammer et al., 2012).

Previous empirical studies use various measures of CSR such as questionnaires (Waldman et al., 2006), KLD database (Ho et al., 2012), DJSI (Chih et al., 2010), and Asset-4 (Ioannou & Serafeim, 2012). In reality, firm CSR engagement ranges from irresponsible behavior such as child labor to philanthropic activities for the society. Instead of trying to come up with a best definition, this study tries to regard CSR engagement as a continuum, which ranges from proactive voluntary action of firms to passive adoption of regulations imposed by law. Consequently, the current study employs two different measures of CSR: high CSR (DJSI database) and average CSR (Ioannou & Serafeim's (2012) database). High CSR corresponds to the upper end of the continuum where firms voluntarily goes beyond what is required by law (CSR leaders), whereas average CSR corresponds to the lower end of the continuum where firms only adopt minimum legal requirements (average CSR performers). Looking at CSR engagement as a continuum rather than a definitive point enables us to reconcile the conflicting findings in the previous studies.

Institutions and corporate social responsibility

Most CSR scholars place more interest in exploring the relationship between CSR and firm financial performance (e.g. Chih, Chih, & Chen, 2010; McWilliams & Siegel, 2001; Surroca, Tribó, & Waddock, 2010). Of the few studies examining the antecedents of CSR, most of them devote their attention to the firm-level variables such as firm size or visibility (e.g., Udayasankar, 2008), prior financial performance (e.g., Chih et al., 2010), research and development capacity (e.g., Padgett & Galan, 2010). Only a handful studies explore institutional level determinants such as political and economic systems (e.g., Ioannou & Serafeim, 2012), and national culture (e.g., Ho et al., 2012; Lenssen et al., 2007).

Institutions are usually defined as formal or informal rules, regulations, norms, and understandings that constrain and enable behavior (Brammer et al., 2012). Formal institutions mainly refer to hard regulations such as laws, standards, etc., whereas informal institutions refer to soft civil regulations such as ethical norms, culture and religion (Gjølberg, 2009). Thus, institutions are also as a continuum that ranges from coercive political regulations to normative influence of society.

The four-level analytical framework of Williamson (2000) proposes the mechanism to explain how informal institutions may affect firm decision-making. Informal institutions such as national culture (level 1), which impose constraints on formal institutions (level 2), governance structure of contracts (level 3), and resource allocation decisions (level 4, e.g., the decision to engage in CSR) are the most fundamental level. Because of bounded rationality, it is impossible to contract for all contingencies, which undermines the ability of formal rules, and necessitates the use of informal rules in governing economic outcomes (Williamson, 1998). To put it simple, culture complements formal institutions in situations where formal institution fails to operate.

Hall and Soskice (2001) argue that institutions shape the nature of coordination among corporate stakeholders, and identify different varieties of capitalism that are liberal market economies (LME) and coordinated market economies (CME), which in turn influence different types of CSR engagement. Based on the logic of Hall and Soskice (2001), Gjølberg (2009) shows that CSR engagement mirrors institutions, whereas Jackson and Apostolakou (2010) indicate that CSR substitutes institutional regulations in forms of firms' self-governance. Table 1 summarizes the findings of previous literature on institutional level antecedents of CSR.

Although the main premise of institutional theory indicates that formal and informal institutions work together as one system by complementing each other, previous studies tend to focus either on the influences of formal institutions or of informal institutions. For example, Ioannou & Serafeim (2012) focus on the impacts of formal institutions such as legal, labor, and capital market institutions, while they pay less attention to informal institutions. Similarly, Chih et al. (2010) explore the impacts of education, law enforcement, and economic environment in relation to CSR, without paying particular attention to informal institutions. On the contrary, three pioneering studies place more emphasis on the relationship between national culture and CSR (Ho et al., 2012; Lenssen et al., 2007; Waldman et al., 2006), but putting less concern on the impact of formal institutions.

After conducting a comprehensive review of 180 national culture empirical studies published on top ranking journals, Taras, Kirkman, and Steel (2010) raise a call for exploring conditions under which culture matters. Depending on the circumstances, institutional variables may complement or substitute one another. Consequently, several studies respond to the call from Taras et al. (2010) to explore the mechanism through which formal and informal institutions work together to govern firm behavior (Gjølberg, 2009; Ioannou & Serafeim, 2012). However, none of these studies further explores the substitution or interaction effects among national culture and other institutions.

Methods

Testing the institutional configurations on CSR performance presents methodological challenges related to analytical strategy. Most theories in management do not correspond to linear model of reality presupposed by MRA (Gjølberg, 2009; Ragin, 2000).

Sample and data collection

The current research collected data from a number of databases. Regarding CSR measurement, we used two sources of CSR databases. The first source of CSR, Dow Jones Sustainability Index (DJSI), only incorporates top 10-15% of listed firms engaging in CSR; the second source of CSR is from Ioannou and Serafeim (2012), which adopt a continuous measure for firm CSR engagement. Compared to Ioannou and Serafeim (2012) country average score, DJSI adopts a stricter standard to evaluate firm CSR engagement. With respect to institutions, cultural values data is from Hofstede (2001), economic prosperity data from WorldBank, innovativeness data from Global Innovativeness Index (GII), and law enforcement data and educational data from Global Competitiveness Yearbook 2009. The final sample consists of 32 developed and developing countries with firms listed in S&P Global 1200 index in 2010.

Comparative method

FsQCA has several advantages over MRA (Ragin, 2000; Woodside, 2013). Due to sample size limitations, few studies test the higher order interaction effects with MRA (Ragin, 2006). fsQCA can overcome sample size limitations and hence it can test the combined effects of causal factors. Second, fsQCA does not assume symmetry and works well with asymmetric data. In reality, specifically in social science, most cases are asymmetrical (Ragin, 2000; Woodside, 2013). Third, allowing different solutions to the same outcome—principle of equifinality (Woodside, 2014), fsQCA can explore if different configurations of institutional variables lead to the same outcome, CSR engagement. FsQCA calibration of the raw data using previous theoretical and empirical knowledge makes it *half verbal-conceptual* and *half mathematical-analytical* (Ragin, 2000).

Measures

Table 2 summarizes the data of institutional variables. Using the database of Ioannou and Serafeim (2012), the current study calculated and calibrated the means of social, environmental, and governance scores to measure CSR performance, as shown in Table 2. According to the CSR measure of Ioannou and Serafeim (2012), half of the firms in the sampling countries tend to engage in more CSR activities. This measure is consistent with Campbell's (2007) definition of CSR engagement, which requires firms to meet the minimum standards and requirements.

Second, in the current study DJSI[1] is an alternative measure of CSR, which represents a higher standard, compared to the measure of Ioannou and Serafeim (2012), to evaluate firm CSR engagement. We calculate the ratio of CSR leaders to the total firms in a country. Taking United Kingdom as an example, United Kingdom has 99 firms appearing in S&P Global 1200 and 43 of those 99 firms also appearing in DJSI. Thus, the ratio for United Kingdom is 43/99=0.43. We aggregated 1,189 firm data into country-level ratios and subsequently calibrated these scores. According to DJSI methodology, only 10-15 percent of the firms in a particular industry meet the stricter requirements of CSR leaders.

Third, causal variables in this study are four dimensions of national culture: power distance, individualism, masculinity, uncertainty avoidance, and four institutional variables- economic prosperity, law enforcement, education quality, and country innovativeness index. We measure economic prosperity by GDP per capita, law enforcement by crime rate per 10000 people, education quality by quality ranking of management schools, and country innovativeness by GII score. Tables 2 indicates that the institution scores and calibration values. On the theoretical basis, we define the cut-off points to fit our specific sample.

Procedure of the analysis

In order to observe the relevance (importance) of institutional level variables at different level of CSR engagement, we ran two separate fsQCA analyses for DJSI-based CSR (high standard of CSR engagement) and Ioannou and Serafeim-based (2012) CSR (average standard of CSR engagement). In order to identify the interaction and substitution effects among formal and informal institutions on firm CSR engagement, we ran three fsQCA analyses for informal institutions, formal institutions, and the combination of both institutions. We repeated each of these three analyses twice regarding DJSI-based CSR and Ioannou and Serafeim-based (2012) CSR, which produces six different models.

Empirical findings

Table 3 reports the main finding of six models through the analyses of fsQCA. In fsQCA, a researcher usually concludes that a model is informative when consistency is above .75 and coverage is between .25 and .65 (Ragin, 2008).

The first three models report the findings for DJSI-based CSR engagement. Model 1 tests only cultural dimensions with CSR. The only complex antecedent condition is *idv*~mas *uai*, which has coverage (.32) and consistency (.75) scores that satisfy the above criteria. Thus, it confirms that culture, a system of values and beliefs, affects CSR. Model 2 shows that one configuration of formal institutions might affect firm CSR engagement, while the configuration does not meet the requirements of consistency and coverage. Model 3 indicates that the combined effect of formal and informal institutions significantly affect firm CSR engagement. Compared to Model 1 and Model 2, Model 3 offers a better predicting power of firm CSR engagement.

The last three models report the findings for Ioannou and Serafeim-based (2012) firm CSR engagement (average standard of CSR engagement). Model 4 depicts findings on the impacts of cultural values on CSR. In model 4, and one of the two recipes is exactly the same as the one recipe that we obtained in Model 1 with DJSI-based CSR. The solution coverage (.55) and solution consistency (.85) both satisfy the model fit criteria. Model 5 reports the findings on the impacts of formal institutions on CSR. Although the model fit is not as good as Model 4, Model 5 confirms that formal institutions alone can affect average CSP. Model 6 explores the impacts of both formal and informal institutions on firm CSR engagement, which suggests four recipes to facilitate firm CSR engagement. Compared to Model 4, we observe a modest increase in solution coverage and small decrease in solution consistency in Model 6.

Discussion

Although fsQCA recipes cannot directly compare with the findings drawn from MRA, we still try to find if there exist consistent results between the current study and the previous studies. It is noteworthy that our findings can reconcile the conflicting results of previous studies on CSR antecedents. For example, the four recipes in Model 6 explain a negative association between masculinity and firm CSR engagement from Lenssen et al. (2007), and an insignificant masculinity-CSR relationship from Ho et al. (2012). Depending on the configurations among other institutional factors, masculinity can have either a negative or a positive sign. Similarly, this conclusion can apply to other three cultural dimensions as well.

Complementary and substitution effects among formal and informal institutions

Comparing Model 1 and Model 3 horizontally, we find that in the presence of formal institutional variables, individualism changes its sign in the first recipe and disappears from the second recipe of Model 3. It indicates that some formal institution(s) may substitute the influence of individualism on firm CSR engagement. We include an additional test[2] of Model 3 at .75 consistency cut-off into the comparison and obtain a similar conclusion for power distance, law enforcement, education, and innovation since they change their signs in different recipes. An interesting finding is that any combination of other variables cannot substitute for ~mas, uai, and gdp across Model 1 and Model 3. These three factors are consistent across all recipes in Model 1 and Model 3.

An institution with a high feminine value and high uncertainty avoidance culture is more likely to have a greater ratio of CSR leaders. With respect to masculinity, previous research shows that masculinity inhibits helping behavior (Tice, Baumeister, & Zhang, 2004) thus, in general, people from that society also are not likely expect helping behavior from others. High uncertainty avoidance culture always seeks to reduce uncertainties such as environmental hazards and thus tend to value firm CSR activities that reduce the uncertainties. Our findings support Maignan (2001) that employs consumer survey in US, France, German, and Sweden, which finds that French consumers (a high femininity and high uncertainty avoidance culture) are inclined to support firms engaging in CSR activities compared to US consumers (a low femininity and low uncertainty avoidance culture).

Although Model 2 is not informative, the increased explanatory power in Model 3 compared to Model 1 suggests that both formal and informal institutions bring their unique ingredients into the recipes. It indicates that formal and informal institutions complement each other to motivate firms become CSR leaders.

However, the comparison among Model 4, Model 5, and Model 6 produces an opposite finding from the comparison between Model 1 and Model 3, which reveals that both formal and informal institutions can affect firm CSR engagement separately, and most of the cultural and formal institutional variables can substitute each other. All of the institutional variables change their signs in different recipes except for GDP. Moreover, only a marginal increase of Model 6 compared to Model 4 and Model 5 suggests that each of the formal and informal institutions, except for GDP, does not bring a unique ingredient into the recipe. Culture and formal institutions substitute each other in the Model 4, Model 5, and Model 6.

The relevance of institutional configurations on firm CSR engagement

Comparing all models vertically, we can understand the relative importance of institutional variables at two different end of CSR continuum. The vertical comparison reveals that institutional variables better explain average CSR engagement as compared to high CSR engagement. All the coverage and consistency scores of average CSR engagement (Ioannou & Serafeim, 2012) models are higher than their high CSR engagement (DJSI) peer models (Model 1: coverage 0.33, consistency 0.76 versus Model 4: coverage 0.55, consistency 0.85; Model 2: coverage 0.13, consistency 0.71 versus Model 5: coverage 0.41, consistency 0.75; and Model 3: coverage 0.25, consistency 0.85 versus Model 6: coverage 0.60, consistency 0.83). This finding is consistent with Jackson and Apostolakou (2010) that shows institutions better explain average CSR engagement. While institutional effects are important, firm-specific capabilities might better explain why some firms become genuine CSR leaders. Not every firm is capable of doing well by doing good. Figure 1 shows XY plot of cultural recipe *idv*~mas *uai* in relation to high CSR engagement (left), and average CSR engagement (right). The sufficiency of this recipe for average CSR engagement is greater given that there are only 3 dots in the lower right half of the left-hand side plot. It is supposed to be this way. If a certain configuration leads to high CSR engagement, it also has to lead to average CSR engagement since high CSR engagement is a subset of average CSR engagement. It confirms that institutions better explain average CSR engagement.

In summary, societal expectation on firm CSR engagement is a continuum that ranges from low to high expectations. Formal regulations can substitute the lower end of the expectation continuum. Usually the minimum expectations or requirements are institutionalized. The high end of the continuum is unlimited. Responding at the lower of the continuum prevents firms from losing its current level of legitimacy, while responding at the high end of the continuum further enhances firms' legitimacy. However, not every firm has the capacity to do well by doing good. This finding might account for Jackson and Apostolakou (2010) observation that firms under institutional pressure either adopt wide range of CSR practices or refrain from adoption.

Conclusions

The findings of this study confirm that institutional variables impose a systematic pressure on firm CSR behavior. Under different standards of CSR engagement, DJSI-based and Ioannou & Serafeim-based (2012) CSR, there exist complementary and substitution effects among formal and informal institutions, which proves the effect of institutional configurations on firm CSR engagement. Furthermore, the fsQCA analysis suggests that cultural values are greater forces to motivate firms to pursue superior CSR performance, while formal institutions are greater forces to push firms to approach average CSR performance. Economic prosperity of the countries underlies both institutions. Higher end of the societal expectation continuum motivates superior CSR performance because it may payoff in the form of legitimacy if firms comply with those cultural values. Either formal institutions or lower end of the societal expectation continuum push firms to meet average CSR standards because it punishes firms that do not meet the minimum requirements. The insights from this paper demonstrate the effectiveness of using fsQCA for complex management issues such as CSR.

The current study makes contributions to both the CSR theory and the CSR practices. More importantly, this paper responds to the call for investigating the institutional configuration in affecting the degree to which firms will engage in responsible behavior. Empirically, this paper is the first one to provide evidence for the impacts of institutional configurations on firm CSR engagement.

This study has several implications for managers and policymakers. Based on our findings, managers can formulate an effective CSR policy for certain countries or cultures. For example, if a country is characterized by the recipe of pdi*~mas*uai*gdp*~crime*edu*inno, firms engaging in voluntary CSR activities will enhance their legitimacy. Policy makers should consider complementary and substitution effects among institutional factors to encourage firms engaging in CSR activities when making laws and regulations. Moreover, policymakers should understand the limitations of formal institutions if policymakers seek to motivate firms to achieve superior CSR performance.

The current study has some limitations as follows. First, the research sample only includes large publicly traded companies. Thus, the findings from this study are less relevant to small and medium sized firms. Second, due to escalating the analytical unit from a firm to a nation, we cannot directly discuss the influence of firm-specific factors on CSR engagement. Future studies can employ fsQCA to explore firm-level antecedents such as idiosyncratic characteristics on firm CSR engagement, which can enhance our understanding on the influences of resource configurations and/or organizational profile configurations on firm CSR engagement.

Table 1-Institutional antecedents of CSR

Empirical Studies	Ho, Wang, and Vitell, 2011	Ringov & Zollo, 2007	Waldman et al., 2006	Ioannou & Serafeim, 2012	Chih, Chih, & Chen, 2010	Jackson & Apostolakou, 2010	Gjølberg, 2009
Sample	49 nations	34 nations	15 nations	42 nations	34 nations	16 nations	19 nations
Measure of CSR	KLD, IVA, and CSID	IVA Innovest	Questionnaire	ASSET 4	DJSI	DJSI	Several Indices
PDI	+	-	-	+			
IDV	-	n.s.	+	+		Cross country comparison	
MAS	+	-					
UAI	+	n.s.					
GDP					+		+
Law				+	+	-	+
Edu					+		

Table 2 -Summary data for institutional variables

Statistics	CSR_{DJSI}	$CSR_{I\&S}$	PDI	IDV	MAS	UAI	GDP	Crime	Edu	Inno
N Valid	32	32	32	32	32	32	32	32	32	32
Missing	0	0	0	0	0	0	0	0	0	0
Mean	0.23	0.48	51.41	51.22	49.25	64.34	34828	4.86	32.38	4.04
Std. deviation	0.21	0.1	19.52	25.99	20.67	25.41	15563	0.54	27.36	0.66
Minimum	0.01	0.32	11	11	5	8	8519	4.13	1	2.76
Maximum	0.67	0.66	95	91	95	112	80822	6.6	102	4.85
Calibration values at										
95%	0.5	0.6	85	75	85	90	40000	6	80	4.5
50%	0.25	0.5	55	50	55	60	20000	5	50	3.5
5%	0.09	0.4	35	27	35	35	10000	4.3	20	3

CSR_{DJSI} refers to high standard of CSR engagement while $CSR_{I\&S}$ refers to average standard of CSR engagement

Table 3- Findings from fsQCA for institutional antecedents of CSR[a]

	Cultural Institutions	Formal Institutions	All Institutions Combined
	Model 1	**Model 2**	**Model 3[b]**
High CSR Engagement	--- COMPLEX SOLUTION -- - frequency cutoff: 1.000000 consistency cutoff: 0.753049 idv*~mas *uai solution coverage: 0.329202 solution consistency: 0.758928	--- COMPLEX SOLUTION -- - frequency cutoff: 1.000000 consistency cutoff: 0.708333 gdp*crime*~edu*inno solution coverage: 0.131681 solution consistency: 0.708333	--- COMPLEX SOLUTION --- frequency cutoff: 1.000000 consistency cutoff: 0.813954 pdi*~idv*~mas*uai*gdp*~crime*edu pdi*~mas*uai*gdp*~crime*edu*inno solution coverage: 0.253292 solution consistency: 0.851562
	Model 4	**Model 5**	**Model 6**
Average CSR engagement Ioannou & Serafeim, 2012	--- COMPLEX SOLUTION -- - frequency cutoff: 1.000000 consistency cutoff: 0.837209 idv*~mas*uai ~pdi*idv*mas*~uai solution coverage: 0.553036 solution consistency: 0.849438	--- COMPLEX SOLUTION -- - frequency cutoff: 1.000000 consistency cutoff: 0.776167 gdp*crime*inno gdp*edu*inno solution coverage: 0.414777 solution consistency: 0.754993	--- COMPLEX SOLUTION --- frequency cutoff: 1.000000 consistency cutoff: 0.860000 pdi*~mas*uai*gdp*~crime*edu ~pdi*idv*mas*gdp*~crime*edu*~inno ~pdi*idv*mas*~uai*gdp*edu*~inno ~pdi*idv*~mas*uai*gdp*crime*~edu*inno solution coverage: 0.599122 solution consistency: 0.828109

[a] To keep the table concise, the raw coverage, unique coverage, and recipe consistency are not reported.

b For comparison, we ran Model 3 at .75 consistency cut-off. We get the third recipe: ~pdi*idv*~mas*uai*gdp*crime*~edu*inno in addition to two recipes above. The solution coverage and the solution consistency are 0.55 and 0.77 repectively.

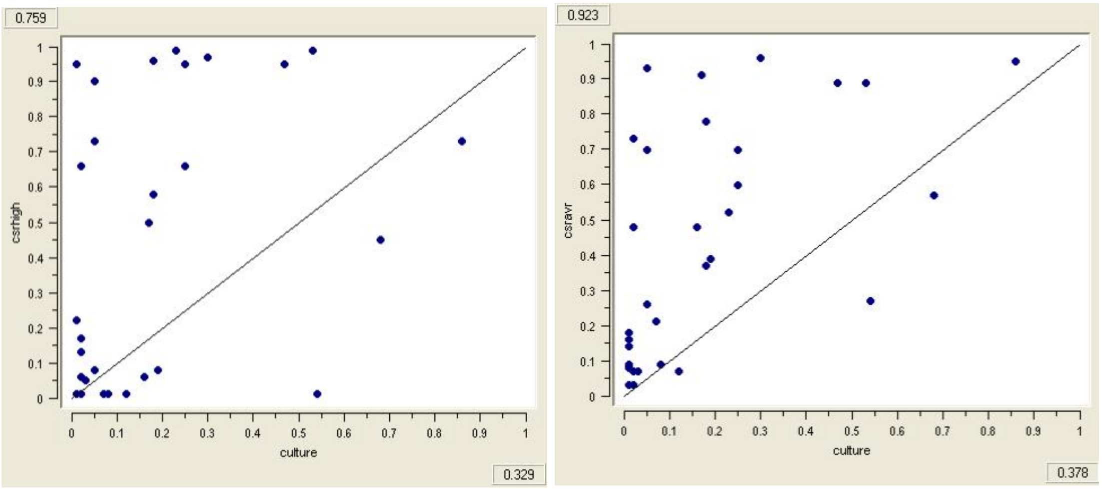

Figure 1-XY plot of idv~mas *uai recipe in relation to high CSP and average CSR.*

Notes

1. ***The S&P Global 1200*** index covers seven distinct regions and more than 30 countries. It captures approximately 70% of the world's market capitalization. Firms are eligible for the S&P global indices if they meet certain criteria for size, liquidity, profitability, and sector and market representation. The most important characteristic of this index is that each of the component indices is balanced across country and sector weights in the region/market. ***DJSI***: A sustainable asset management group (SAM) evaluates the 2,500 largest companies in the Dow Jones Global Index (DJGI) index and selects the firms for the DJSI, which is composed of the top 10% of the leading sustainability firms from 58 industries. The SAM methodology is based on the application of specific criteria to assess the opportunities and risks derived from the economic, environmental, and social dimensions of each of the eligible companies in the DJSI investable stocks universe.
2. For comparison, we ran Model 3 at .75 consistency cut-off. We obtained the following recipes:
   pdi*~idv*~mas*uai*gdp*~crime*edu,
   pdi*~mas*uai*gdp*~crime*edu*inno
   ~pdi*idv*~mas*uai*gdp*crime*~edu*inno.
   The solution coverage and the solution consistency are 0.55 and 0.77 respectively. More information available upon request.

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TRUST AS A GOVERNANCE MECHANISM IN VALUE CO-CREATION: THE NATURE OF TRUSTWORTHINESS SIGNALS AND PROACTIVE TRUST CONSTRUCTION (FP)

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Abstract

Trust has long been viewed as a potential governance mechanism. However, recent research discloses substantive incongruities in trust conceptualization and operationalization. Our goal is to develop an empirically grounded conceptualization of trust and to explore the trust-construction process. We use three related studies—each with an inductive component—to evaluate trust construction. Our findings conclude that there is a divergence in the way companies operationalize trust and the way academics define trust. In the supply chain setting, managers describe trust as consisting of credibility and relationship commitment. Missing is the notion of benevolence. However, ambiguity surrounding trust conceptualization increases the costs and decreases the effectiveness of proactive trust construction.
Keywords: trust, supply chain governance, value co-creation

Companies are just beginning to learn what nations have always known: in a complex, uncertain world filled with dangerous opponents, it is best not to go it alone.
—Kenichi Ohmae, McKinsey & Co.

Introduction

Supply chain collaboration can help companies combine capabilities to co-create value and earn relational rents (Harrison et al., 2001; Fawcett et al., 2012; Mentzer et al., 2008; Devaraj et al., 2007). Many firms, however, struggle to create distinctive value across organizational boundaries (Power, 2005; Fawcett and Magnan, 2004; Jones et al., 2010; Fawcett et al., 2012). Constrained by turf as well as by fear of opportunistic behavior, managers find it difficult to govern resource-sharing relationships (Jones et al., 2010; Fawcett and Magnan, 2001; Read et al., 2014; McLachlin and Larsen, 2011). Specifically, managers do not effectively employ trust as a governance mechanism to build relational capital and effective resource-sharing routines (Gereffi et al., 2005; McEvily and Tortoriello, 2011; Chen et al., 2010; Mesquita, 2007; Voss et al., 2006). Managers must therefore rely on cumbersome contracts to safeguard relationships or they forego investments in relation-specific assets, avoiding the entanglements inherent in interdependent, integrated capabilities (Gereffi et al., 2005; Jong and Nooteboom, 2001; Lambsdorff, 2002; Hoyt and Huq, 2000). Absent trust, collaborative supply chain alliances do not emerge and relational returns are lost (Wallenburg et al., 2011).

Extant research has shown that high levels of trust can improve profitability (Frazier, 1988; Cao and Zhang, 2011; Fawcett et al., 2012), enhance innovation effectiveness (Cao and Zhang, 2011; Wang et al., 2011), and promote more collaborative, higher-performing supply chain relationships (Barczak et al., 2010; Fawcett et al., 2006; Wang et al., 2011; Jones et al., 2012;). By contrast, research has documented the cost of low or lost trust (Chen et al., 2011). For example, in the egregious case of General Motor's J. Ignacio Lopez, the early 1990s decision to tear up existing supplier contracts in order to pit suppliers against each other to lower the cost of purchased goods damaged GM's reputation among suppliers for over a decade (Magnan et al., 2011; Carter, 2000; Jin et al., 2013). Now, the conundrum: The extant research as well as managerial anecdotes demonstrate two vital gaps in our understanding of how to use trust as an effective governance mechanism.

1. **Conceptualization Gap.** Although academics have long and frequently investigated trust as a foundational relational building block (Narasimhan et al., 2008; Fawcett et al., 2012), recent research argues that trust conceptualizations lack consistency (Whipple et al., 2013; Delbufalo, 2012; McEvily and Tortoriello, 2011). Moreover, trust measurement is rudimentary (McEvily and Tortoriello, 2011;) and trust scales are underdeveloped (Ferin, 2013).
2. **Construction Gap.** Although managers talk "knowingly" about trust as a precursor to alliance success, they admittedly do not grasp how to proactively cultivate trust as an effective governance mechanism (Jones et al., 2014; Day et al., 2013; Fawcett et al., 2012; Voss and Williams, 2013).

Given trust enables collaborative gains (or losses), the time has come to close both gaps by taking a closer look at 1) trust conceptualization in the supply chain context as well as 2) the processes and behaviors inherent in the trust-construction process.

Therefore, our purpose is twofold: 1) to enrich understanding about trust's role as a governance mechanisms and collaborative enabler (i.e., what is trust?) and 2) to explore the dynamics of the trust-construction process (how does trust emerge?). To do this, we use a longitudinal, multi-method approach to revisit trust conceptualization in supply chain relationships. We contribute to the study of trust's role in relational advantage in three ways. First, we propose a refined, capabilities-based conceptualization of inter-organization trust. Second, we develop a proactive, signaling-based framework for constructing supply chain trust. Third, we document bias in the way managers assess and interpret trustworthiness signals, demonstrating a need to research trust using multiple key informants across relationships.

Trust Construction and Relational Advantage

The capabilities literature clarifies trust's role as a governance mechanism as well as its contribution to collaboration and competitive advantage. Three points are particularly relevant.

1. **Distinctiveness**. The essence of the resource-based view is that firms that possess valuable, inimitable, rare, and non-substitutable (VRIN) resources outperform rivals (Wenerfelt, 1984; Barney, 1991).
2. **Resource Access**. Dyer and Singh (1998, p. 650) emphasize that the capabilities needed to achieve a VRIN advantage are often "*embedded in inter-firm resources and routines*."
3. **Resource Configuration**. Later RBV research stresses terms like "combine," "coordinate," "integrate," and "reconfigure" to explain the *dynamic* process of *how* firms deploy resources to develop VRIN capabilities (Eisenhardt and Martin, 2000; Ettlie and Pavlou, 2006; Newbert, 2007). In fact, Baretto (2010: 271) highlights rapid resource reconfiguration as vital to developing a dynamic capability, which he defines as "a firm's ability to systematically solve problems, formed by its propensity to sense opportunities and threats, to make timely and market-oriented decisions, and *to change its resource base*."

How does trust fit in the capabilities conversation? Governance mechanisms—e.g., contracts and trust—promote or hinder the collaboration required to access and reconfigure inter-firm resources (Gulati and Singh, 1997). Trust, in particular, reduces governance costs and promotes agile and creative relationships (Barney and Hansen, 1994; Doney and Cannon, 1997; Anand et al., 2012). Trust enables the rapid reconfiguration of inter-firm resources needed to develop distinctive, innovative capabilities and gain advantage in a fiercely competitive, dynamic marketplace (Eisenhardt and Martin, 2000; Fawcett et al. 2012). To employ trust as an enabler of value co-creation and relational advantage, managers must understand 1) its nature and 2) how to proactively construct it when unique value-co-creation opportunities exist.

Trust as a Governance Mechanism

Given its central role in relationship governance, scholars in fields from sociology and psychology to economics and management have examined the nature of trust. The diversity of these fields raises the concern, "Are researchers across—as well as within—domains examining the same phenomena?" To probe this issue, we searched ten leading management journal—going back to 1972—for trust-related research. Following the article–selection methods outlined by David and Hahn (2004), we reviewed a total of 234 relevant trust articles. We classified these articles by trust types (context) and research method (see in Table 1). Two key findings emerged.

1. **Different Contexts/Different Phenomena**. Researchers have delved into at least five distinct types of trust: general trust (45 articles), interpersonal (78), Intrafirm (37), inter-organizational (83), and individual to firm. Each trust type performs similar, but unique roles, revealing that, "Trust scholars are not exploring a singular 'trust' phenomenon!" Further, many diverse trust dimensions are being explored, measured, and labeled as trust.
2. **Influence of Interpersonal Trust**. Despite the fact that person-to-person and firm-to-firm contexts—i.e., behaviors, goals, and structures—are distinct, conceptualizations of inter-organizational trust draw heavily from the inter-personal trust constructs of credibility and benevolence. Credibility is the confidence that each party in a relationship will perform as promised. Benevolence refers to the mutual expectation between two parties that each will act in the other's best interests as decisions are made.

   Table 2 shows that the many of the most-frequently cited inter-organization trust articles in the marketing, management, and supply chain disciplines rely on the notions of credibility (also described as performing to promise and integrity) and benevolence (also viewed as goodwill and non-exploitation). Some of these trust facets—like performing to promise—appear to transfer readily from inter-personal to inter-organizational contexts. Others—such as benevolence—may not. Honda's Dave Nelson, for example, consistently emphasized that buyer/supplier relations cannot be based on benevolence (Nelson et al, 1998).

Table 1 - Categorization of Trust Literature: Trust Type by Methodology

	General Trust	Interpersonal	Intra-firm	Inter-organizational	Individual-to-Firm	Total[2]
Conceptual/Theoretical	44	16	9	14	1	*84*
Survey	0	42	17	50	8	*117*
Case/Interview	0	8	10	13	0	*31*
Behavioral	0	12	0	5	2	*19*
Archival	1	0	1	1	0	*3*
Total	*45*	*78*	*37*	*83*	*11*	*254*

[1] *Academy of Management Journal*, *Academy of Management Review*, *Administrative Sciences Quarterly*, *Journal of Management, Journal of Marketing*, *Journal of Marketing Research*, *Journal of Operations Management*, *Journal of Supply Chain Management*, *Organization Science*, and *Strategic Management Journal*

[2] 20 Multi-method papers (11 survey/case; 9 survey/behavioral experiment)

149 Empirical (125 cross sectional; 24 longitudinal / 98 monorespondent; 51 dyadic)

51 Dyadic (22 interpersonal; 7 intra-firm; 21 inter-organizational; 1 person-to-firm)

Table 2 - Representative Conceptualizations of Inter-organizational Trust

Author(s)	Definition	Conceptualization	Cites
Marketing			
Anderson & Narus (1990)	A firm's belief that another company will perform actions that will result in positive outcomes for the firm, as well as not take unexpected actions that would result in negative outcomes for the firm.	• Performance to Promise • Benevolence	5035
Ganesan (1994)	The willingness to rely on an exchange partner in whom one has confidence.	• Credibility • Benevolence	4907
Morgan & Hunt (1994)	Trust exists when one party has confidence in an exchange partner's reliability and integrity.	• Credibility • Integrity	12709
Kumar et al. (1995)	The belief that the partner stands by its word, fulfills promised role obligations, and is sincere. In addition, the partner is interested in the firm's welfare and will not take unexpected actions that will negatively affect the firm.	• Honesty • Benevolence	1296
Ganesan & Hess (1997)	Trust is composed of an expectancy held by an individual or group that the word, promise, verbal or written statement of another party can be relied on, and a confidence in the motives of the other party in conditions involving risk or a belief in the benevolent intentions of the other party.	• Interpersonal Trust • Interpersonal Benevolence • Organizational Trust • Organizational Benevolence	388
Doney & Cannon (1997)	The perceived credibility and benevolence of a target of trust.	• Credibility • Benevolence	4703
Jap (1999)	The ability to predict the actions of the other party in the relationship reliably and the belief that the other party will not act opportunistically if given the chance.	• Interpersonal Trustworthiness	786
Grayson & Chen (2008)	We define "trust" as a belief that an exchange partner is benevolent and honest.	• Benevolence • Integrity	85
Management			
Ring & Van de Ven (1992)	Confidence in the other's goodwill.	• Fulfilling commitments • Goodwill	2731
Mayer *et al*. (1995)	Willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party.	• Capability • Benevolence • Integrity	8744
McAllister (1995)	The extent to which a person is confident in, and willing to act on the basis of, the words, actions, and decisions of another.	• Affect-based • Cognition-based	3882
Cummings & Bromiley (1996)	An individual's belief or a common belief among a group of individuals that another individual or group (a) makes good-faith efforts to behave in accordance with any commitments both explicit or implicit, (b) is honest in whatever negotiations preceded such commitments, and (c) does not take excessive advantage of another even when the opportunity is available.	• Fulfilling commitments • Goodwill • Non-exploitation	976
Zaheer *et al*. (1998)	Expectation that an actor can be relied on to fulfill obligations, will behave in a predictable manner, and will act and negotiate fairly when the possibility of opportunism is present.	• Performance to Promise • Predictability • Non-exploitation	2555
Ireland et al. (2002)	Trust is a willingness to accept vulnerability based upon positive expectations of partner behavior. Predictability, dependability, and faith are three key components of trust. When trust exists, the firm does not fear its partner's actions, because the partners can depend on each other to achieve a common purpose.	• Performance to Promise • Non-exploitation • Goodwill	899
Dyer & Chu (2003)	One party's confidence that the other party in the exchange relationship will not exploit its vulnerabilities.	• Non-exploitation	738
Lui & Ngo (2004)	Expectation of a partner fulfilling a collaborative role in a risky situation, and [the reliability] of both the partner's intention to perform and its ability to do so.	• Competence • Goodwill	191
Krishnan et al. (2006)	The expectation held by one firm that another will not exploit its vulnerabilities when faced with the opportunity to do so.	• Non-exploitation	365
Puranam & Vanneste (2009)	The expectation that an exchange partner will not behave opportunistically, even when such behavior cannot be detected by the victim.	• Non-exploitation	90
Supply Chain			

Whipple & Frankel (2000)	Trust exists in two forms, one pertains to the qualitative characteristics of behavior inherent in partners' strategic philosophies and cultures, the other regards specific operating behaviors and day-to-day performance.	• Character-based • Competence-based	267
Johnston et al. (2004)	Each party in the chain has mutual confidence in the other members' capabilities and actions.	• Dependability • Benevolence	414
Gattiker et al. (2007)	Most definitions converge on two main dimensions: first, the idea of a belief in the other party being honest, dependable or reliable and, second, the belief that the other party would not take advantage of an opportunity to gain at the other party's expense, given the chance. We refer to [the first] dimension as honesty trust. We label the second dimension benevolence trust.	• Integrity • Benevolence	74
McCarter & Northcraft (2007)	A psychological state where a party is willingly vulnerable to behavior of another party because of expected cooperation / benevolence from that party.	• Cooperation • Benevolence	89
Hill et al. (2009)	We define trust here as a firm's reliance upon other entities with which it is engaged to voluntarily recognize and protect its rights and interests (Hosmer, 1995).	• Benevolence	56
Nyaga et al. (2010)	Trust refers to the extent to which relationship partners perceive each other as credible and benevolent. Credibility reflects the extent to which a firm in a relationship believes that the other party has the required expertise to perform the expected task effectively, while benevolence occurs when one relationship partner believes that the other party has intentions and motives that will benefit the relationship.	• Credibility • Benevolence	152
Other			
Larzelere and Huston (1980)	Generalized trust is a person's belief about the character of people in the aggregate, while dyadic trust refers specifically to a partner's honesty and benevolence.	• Dyadic Trust	849
McKnight et al. (2002)	Trust is multi-faceted and complex. It had been defined as a tendency to trust others, a cognition about the trustee, and a characteristic of the institutional environment.	• Disposition to trust • Institution-based trust • Trusting beliefs • Trusting intentions • Trust-related behaviors	2012

Potential phenomenological incongruities have led researchers to reassess existing conceptualizations of inter-organizational trust. For example, Seppanen et al. (2007) evaluated 15 seminal inter-organizational trust studies conducted from 1990 to 2003. They deduced that trust is a complex concept that is essential to relationship quality and performance. However, they note that major inconsistencies in conceptualization, operationalization, and measurement persist. McEvily et al. (2011) reviewed a 171 trust articles, finding that limited consensus on operational dimensions exists (they identified 129 different measures of trust). They concluded: “The state of the art of trust measurement is rudimentary and highly fragmented.” Whipple et al. (2013) focused on 42 inter-organizational trust papers published in supply chain journals. They noted that although trust is complex and multi-faceted, 39 out of 42 studies operationalized trust as a single construct. They noted: “All too often content validity is less than adequate. It appears as though we are not always measuring what we want to.” Challenging extant conceptualizations of trust, Whipple et al. asked, “Can we trust them?”

To summarize, trust is widely perceived as a vital governance mechanism that enables firms to work together to co-create unique value. Trust is generally considered to consist of credibility and some form of other-regarding behavior. In the inter-personal context, benevolence is the consensus other-regarding behavior. Despite questionable transference, benevolence is often used in inter-organizational contexts as well. Goodwill and non-exploitation are other frequently used other-regarding behaviors. However, beyond the basics, the literature is fragmented—no consensus regarding trust dimensions or measurement has emerged. As trust influences investments in trust construction, a more systematic approach to conceptualization—one that is grounded in supply chain relational behavior—is needed.

Proactive Trust Construction

Scholars recognize that inter-organizational trust is influenced by the predictability of each party's actions (e.g., Zaheer et al., 1998; Dyer and Chu, 2003). By purposely signaling *trustworthy* behavior and assessing partner reciprocation, managers can proactively construct trust. If both parties exhibit trustworthy behavior, they engender trust, which can be leveraged as a governance mechanism to enable value co-creation (Fawcett et al., 2012). Trustworthiness—the behaviors displayed by a firm that signal it can be trusted—becomes the focal point of proactive trust construction. Trust construction is thus a strategic choice (Jones et al. 2014).

Of note, Doney and Cannon (1997) identified five processes managers use to evaluate partner trustworthiness (see Table 3). These evaluation processes tend to be passive, seeking to avoid risks of exploitation rather than to construct trust as an enabler of inimitability (McAllister, 1995; Dirks, 2000). Managers can, nonetheless, glean insight from them to proactively project trustworthiness via appropriate signals (Johnston, et al., 2004; Jones et al., 2010). To the extent that buying firms can signal that trustworthy behavior is embedded in their company culture, systems, and processes, they can cultivate high levels of supplier trust (Zaheer et al., 1998).

Table 3 **-** *Processes Used to Evaluate Partner Trustworthiness*

Process	**Description**	**Proactive Action**
Calculative	Partners assess the costs and rewards related to opportunistic behavior. When the costs of cheating exceed benefits, decision makers assume they can trust a partner.	Include a "reverse" penalty clause in a supply contract that disciplines the buying firm for non-compliance to promised performance.
Prediction	Partners evaluate each other's past promises and behavior in order to predict future behavior and thus decide whether to trust each other. Iterative experience provides greater insight and thus greater confidence in the prediction.	Publish past promises and performance statistics, thus making it easier and less costly for suppliers to accurately predict the buying firm's future behavior.
Capability	Partners gauge each other's ability to fulfill obligations. If a partner has the ability, performance is expected and trust is granted.	Establish transparent processes and consistent policies to make it easier for suppliers to gauge buyer capabilities.
Intentionality	Partners consider each other's root motives. Intentions become the key to deciding whether to trust or not.	Establish transparent processes and consistent policies to make it easier for suppliers to attribute buyer intentions.
Transference	In the absence of experience working together, partners may ascribe trustworthiness to a partner based on a third party's assertion that trust is warranted.	Broadcast trustworthiness using partner referrals. Leverage reputation.

Given inter-firm dynamics, however, a trust-construction capability is likely difficult to build, requiring appropriate, persistent signaling (Day et al. 2013). As such, trust may be viewed as an operant resource; i.e., a higher-level resource that acts on and increases the value of other (operand) resources. Trust construction, in turn, may convey the strategic benefits of a dynamic capability, empowering a network to act as "one" and promoting the resource reconfiguration needed to respond to a dynamic environment more adroitly than competing supply chains (Doney and Cannon, 1997; Read et al. 2014). The resulting trust-based relationships reduce relational conflict (Zaheer et al., 1998), lower governance costs (Dyer and Chu, 2003), increase inter-firm learning (Dodgson, 1993), and improve relationship satisfaction, and enhance firm performance (Johnston et al., 2004).

Methods

To move toward a more robust conceptualization of inter-organizational trust and the systematic development of trustworthiness measures in the relational supply chain context, we first interviewed companies who are considered leaders on collaboration within their respective industries (Yin, 1984). Evidence obtained from these interviews are further refined through a series of multi-informant studies (Kaufmann and Saw, 2014). We utilized focus groups composed of supply chain managers to further distill trustworthiness dimensions generated from interviews. These trustworthiness dimensions are then used in two dyadic case studies for us to gain a more dynamic view of the trust construction process in supply chain governance. We detail our specific approach to the above combination of studies below.

Identifying Trustworthiness Dimensions

We began by conducting an exploratory inductive study of supply chain relational advantage. Theoretical sampling was employed. That is, we purposely selected 51 companies based on their reputation as collaborative exemplars. The unit of analysis was the firms' approach to value co-creation. Before each interview, managers were emailed a copy of the semi-structured interview guide. The typical interview lasted 2 hours and focused on the issues—e.g., goals, benefits, impediments, and architecture—that influence their company's ability to leverage inter-firm resources for relational advantage.

We carefully transcribed notes from each interview for later analysis and reflection. We also collected other relevant documents—e.g., supplier scorecards, supplier development plans, PowerPoint decks on relationship strategies—to provide context. Individual case studies were written up. Finally, we coded each interview, going from open codes to more theoretical constructs. Trust emerged as the most common enabler of value co-creation and relational advantage. Importantly, recognizing the importance of trust to resource co-mingling, managers described elements of purposeful trust construction. We therefore sought to identify general behaviors/practices (e.g., perform to promise, open information sharing) used to signal and/or assess partner trustworthiness. These behaviors/practices became potential levers or signals that companies can use to build trust as a supply chain governance mechanism.

Refining Content of Trustworthiness Dimensions

Given the exploratory and expansive nature of the interviews, we recognized a need to refine our developing understanding of trust dimensions. We used the emerging insight from the interviews to organize a trust construction diagnostic. That is, for each dimension, we identified behaviors interview companies manifest to engender trust for relational governance. These signaling behaviors became individual questions. We used this trustworthiness diagnostic in a series of 11 focus studies with buyers and senior supply chain executives. Participants were recruited from both local and national affiliates of various supply chain industry groups, such as the Institute for Supply Management. To ensure the content relevance of focus group discussions, only professionals who are actively engaged in managing day-to-day relationships with external supply chain partners participated. The focused discussions lasted from 60-90 minutes and involved from 8 to 45 managers (Mean=26; Total=282).

At the beginning of each discussion, we discussed trust's role as a governance mechanism. Then we discussed with the session participants each of the dimensions (and items) derived from the interviews and contained in the diagnostic. During these focused discussions, participants were encouraged to 1) discuss/explore each trustworthiness dimension with the facilitator, 2) comment on the specific behaviors used to signal trustworthiness, and 3) assess their own firms' trustworthiness signaling behavior. The discussions were wide open and dynamic. Managers asked for clarification, offered examples from their own experience, and suggested additional behaviors they felt manifest trustworthiness. Across the eleven focus groups, we improved the diagnostic's structure as well as the descriptions of individual behaviors. Managers expressed confidence that the diagnostic captured the essence of supply chain trust.

Assessing Dynamics of Trust-Construction

The final study consisted of two dyadic case studies. Two firms—each with an acknowledged reputation as an industry leader in terms of trustworthiness and performance—agreed to participate. The researchers met with key thought leaders within each firm to explain the goals of the study. These senior managers arranged for interviews with appropriate key informants within the focal firms. They also provided a contact list of over 100 supplier account managers. Each of these account managers received an invitation to participate in the study. The invitation asked for an honest appraisal and promised complete confidentiality. After this initial contact, no individual from the focal firm had any further contact with the suppliers. Further, to assure anonymity, we only interviewed a subset of the 100 suppliers on each list. Participation rates were very high.

The interviews were conducted both in person and by phone using the diagnostic, which was augmented by four open-ended questions designed to identify additional signaling behaviors as well as industry best practice. This approach provided a consistent discussion guide while allowing managers to elaborate on how trustworthiness is signaled as well as how trust develops and is sustained over time (Eisenhardt, 1991). Overall, we spent about 45 hours gathering data at buyer firms and another 200 hours with supply managers. The two case studies are briefly described below. The data analysis followed the same process as used in our initial study.

- *Case #1:* This retailer has a large, professional purchasing organization and a billion dollar spend. Supplier relationships are managed vertically. Therefore, the internal discussions regarding buyer trustworthiness were carried out with three groups of managers: 44 buyers, 38 vice presidents, and 5 executive vice presidents. Managers from 68 suppliers participated in the assessment. Only two suppliers who were contacted by the research team declined to participate, yielding a 97% participation rate.

- *Case #2:* This privately held 3rd-party services company has approximately $500 million in sales worldwide. The company takes great pride in its ability to establish close, collaborative relationships. Supplier relationships are managed cross functionally. Therefore, the internal discussions were with four marketers and nine supply chain managers. Managers from 63 suppliers took part (95% participation rate).

To summarize, the three studies combine to provide grounded insight into 1) the conceptualization of trustworthiness signals, 2) the behaviors/practices that compose them and 3) the nature of proactive trust construction as a governance mechanism and enabler of value co-creation across supply chain partners.

Managerial Understanding of Trust as a Governance Mechanism

During our interviews, we asked managers to discuss keys to buyer/supplier alliance success. Three foundational learning points emerged. First, managerial understanding of trust as a proactive governance mechanism is nascent. Managers invariably identified trust as a vital mechanism for governing value co-creation relationships. They likewise noted that a lack of trust prevents two companies from engaging in effective and meaningful collaboration. However, as we explored trust more deeply, managers described the essence or foundation of trust as "doing what you say you are going to do." When pressed further, few managers could elaborate on the investments required to proactively deepen trust. That is, managers did not view trust as a strategy or as a governance mechanism that they could (or should) proactively invest in. Instead, managers discussed trust as a rare phenomenon. They indicated that they have a deep-seated fear of exposing vulnerabilities to potential acts of opportunism. Hence, an inherent paradox exists in which managers would like to employ trust as a collaborative governance mechanism but they are reticent to do so due to a sense of instinctual self-preservation—that is, they fear the negative consequences of misplaced trust.

Second, managers perceive trust differently from the academic definition. That is, as noted above, the literature consensus is that credibility and benevolence comprise trust (e.g., Doney and Cannon, 1997; Johnston et al., 2004). Managers in the interviews, focus groups, and case studies confirmed credibility's contribution to trust development. Managers, however, consistently challenged the existence of benevolence in supply chain relationships. One manager summarized the general view, "Companies don't have friends, they have interests. You can't expect others to do what is right for you if it isn't also the right thing for them." Managers reasoned that in today's fiercely competitive marketplace firms cannot afford to work with partners based on benevolence. Managers emphasized that trust emerges over time from behavior—not benevolence.

Third, managers argued that deep relationships must be built on a solid business case and that trust construction is behavioral—that is, a manifest capability rather than a communicated intent. Indeed, managers indicated that trust is not simply a switch to be turned on and off. Thus, a limited or inadequate conceptualization of trust and the trust-construction process may hinder trust's emergence as a proactive governance lever. Nonetheless, managers recognized that certain behaviors antecede trust. For instance, managers discussed the fact that partners in a trust-based relationship must perform to promise. Over promising and under delivering quickly undermines credibility and value co-creation. Likewise, managers instinctively perceive that behaviors indicate/signal partner trustworthiness. Managers expressed the idea that "Trust is more than a word. It is behavior." They want to see that supply chain partners really view their company as a "valued team member." Managers noted that when both sides of a buyer/supplier relationship observe positive behavioral signals over time, they become more vested in engaging in trust-based rather than contractual governance.

In summary, a synthesis of these three learning points suggests that whereas unique value co-creation potential provokes partnering firms to align interests and goals, misconceptions and incongruities regarding the nature of trust and its development as a governance mechanism impede efficient value co-creation and the generation of relational rents. Ultimately, the need exists to identify and define specific trustworthiness behaviors so that managers can more effectively signal trustworthiness and read partner signals. Likewise, a better conceptualization of the signaling-reciprocating process is critical to proactively establishing trust over time.

A Multi-Informant Perspective of Trust Construction

To go beyond our emerging understanding that trust is behavioral to defining the dimensions of trust (and thus a trust construct), we sought to empirically refine our understanding of trustworthiness signals and how they are employed to engender trust. We pursued this goal through eleven focus-group discussions with supply professionals.

Trustworthiness Dimensions/Signals

Our focus groups helped us to translate the specific behaviors identified in the interviews into patterns of behavior that we labeled as trustworthiness signals. Vitally, managers demonstrated a high degree of agreement on the types of behaviors that signal trust. Continued discussion revealed that these trustworthiness behaviors/signals coalesce into two core trustworthiness-signaling capabilities. Figure 1 depicts this capabilities-based view of trust. Performance capability was perceived as the sine qua non of trust. If a company does not perform to promise, other signals are rendered meaningless.

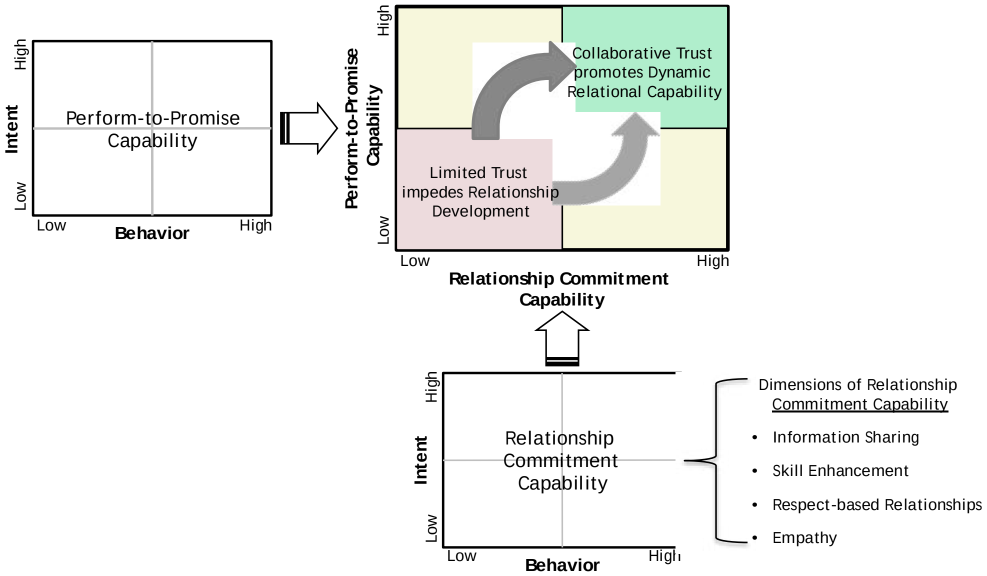


Figure 1 - A Capabilities-based Perspective of Trust Development

Beyond performance, managers described a multi-faceted relationship commitment capability. Both performance and relationship commitment are needed to translate unique value co-creation potential into relational rents. Managers described relationship commitment as manifest via the following behavioral patterns:
1) open information sharing,
2) investments in partner skills,
3) the cultivation of respect-based interpersonal buyer/supplier relationships, and
4) empathy in the decision-making process.
These behaviors represent the dimensions of a trust-signaling construct. They are also relational investments, which project trustworthiness and invite reciprocity. As trust grows, relationship intensity increases. So too does the opportunity to leverage collaboration for value co-creation.

Importantly, managers also described a situation where performance and relationship-commitment capabilities consist of intent and behavior. One manager explained, saying trust "is being able to work together with a high level of confidence that people are going to do what they say they are going to do. It involves both intent and capability to fulfill to what is said." Another reiterated, "Trust is both attitude and capability." Focusing on performance capability, supply chain partners must possess a genuine intent to provide remarkable performance and build the systems and processes that make performance to promise possible. A failure of intent or capability diminishes credibility and limits trust. Regarding relationship commitment capability, managers offered two caveats. First, a gap often exists between earnest intent and lip service to strong relationships. One manager said, "The CEO's talk does not trickle down to day-to-day behavior." Second, many partners lack the skills to convert intent into behavior. Poor communication, short-term thinking, and misaligned metrics undermine relationship commitment. Of note, managers related that strong performance capability motivates relational investments and acts as the springboard for collaborative trust.

Throughout the eleven focus studies, managers were asked to evaluate their own behaviors as indications of their ability to signal trustworthiness. The specific items corresponded to behaviors identified in the interviews. Five-point scales were employed (anchors corresponded to low and high trust behaviors). Table 4 displays the results of these trustworthiness assessments. Of note, the average summated trustworthiness score is 29.11. Only three of the eleven focus groups achieved a score higher than the midpoint of 30. None of these were significantly higher. The low scores suggest that on average companies do not signal trustworthiness. In other words, companies have yet to proactively invest in trust as a governance mechanism. The focus-group discussions revealed two explanations for the lack of effective trustworthiness signaling.

1. **Lack Buy-in**. Many managers indicated that although they personally were interested in trust (thus their agreement to participate in the focus studies), their companies did not view trust as a viable or valued governance mechanism. As a result, it is difficult to motivate firm-wide resource dedication to trust-building initiatives.
2. **Lack Know-how**. Most managers expressed a clear and strong desire to understand better how to build trust. However, they do not fully comprehend the trust signaling process. In particular, confusion persists regarding which behaviors signal trust, how to read partners' signals, and the iterative nature of the trust-construction process.

Further examination of the trustworthiness self-evaluations reveals that none of the 10 behaviors included on the diagnostic obtained an average score of 3.50. Rather, scores ranged from 2.33 to 3.37. Importantly, two of the top three most highly evaluated behaviors—culture of information sharing (3.28) and consider impact of decision on supplier (3.29)—shared the trait of intangibility. In other words, managers expressed a degree of social desirability bias. That is, few

Table 4 - Results of the Focus-Group Self-Evaluations of Trustworthiness

	Focus Groups											**Weighted Average**
	1 n=33	2 n=46	3 n=8	4 n=30	5 n=16	6 n=45	7 n=28	8 n=10	9 n=18	10 n=13	11 n=35	**Total n=282**
Performance Capability												
Perform to Promise	2.58	2.30	2.75	2.33	3.67	2.56	2.79	3.20	2.56	3.15	3.23	**2.72**
Relationship Commitment Capability												
Information Sharing												
Culture of Open Information Sharing	3.55	2.30	3.75	3.53	3.40	3.31	3.57	3.40	3.22	3.77	3.46	**3.28**
Shares Relevant Decision-Making Information	3.42	2.74	4.00	3.53	2.73	3.00	2.86	2.60	2.33	3.46	3.40	**3.08**
Skill Enhancement												
Joint Improvement Risk & Reward Sharing	2.09	2.91	3.00	3.33	3.40	1.58	1.86	1.40	2.11	1.92	2.20	**2.33**
Invest in Supplier Capabilities	2.56	3.04	2.75	2.33	2.60	2.38	2.21	1.80	2.44	1.92	2.31	**2.46**
Interpersonal Relationship												
Encourages Respect-based Relationships	2.39	3.17	3.50	3.07	3.00	2.60	2.07	2.60	2.56	2.85	2.83	**2.75**
Measures Buyer Trustworthiness Behavior	2.52	3.22	3.75	2.73	2.60	2.42	2.64	2.60	3.11	2.85	2.94	**2.80**
Empathy												
Price-Establishing Behavior	3.30	2.91	2.75	2.33	3.13	3.53	3.57	2.40	2.56	2.85	3.00	**3.04**
Supplier-Payment Behavior	3.06	3.00	4.00	3.00	2.87	4.11	3.29	3.60	3.22	3.77	3.51	**3.37**
Consider Impact of Decisions on Supplier	3.06	3.61	3.50	3.2	3.53	3.36	3.07	3.40	2.89	3.46	3.17	**3.29**
Average Trustworthiness Score	**28.53**	**29.22**	**33.75**	**29.38**	**30.93**	**28.84**	**27.93**	**27.00**	**27.00**	**29.90**	**30.06**	**29.11**

managers want to describe themselves or their personal behavior as untrustworthy. Indeed, all three items that compose the empathy dimension scored higher than 3.0. By contrast, the more concrete—that is, easily measured—behaviors like invest in supplier capabilities (2.46) and risk and reward sharing (2.33) obtained the lowest mean scores.

To summarize, the capabilities-based view of trust that emerged from the focused studies yields two vitals insights. First, a focus on behaviors and capabilities provides the basis for a more robust conceptualization and operationalization (i.e., both measurement and process) of trust. Second, measuring the signaling behaviors that underlie trust development informs the reason why firms have largely failed to use trust as a viable governance mechanism. Simply stated, few firms' behavior actually signals that they want to collaborate and that they can be trusted as value co-creation partners.

Trust Construction

Having empirically derived our conceptualization of trust, we sought to delineate the trust-construction process. Pursuant to a theoretical approach, we identified two companies known for developing strong buyer/supplier relationships. Arguably, each company was recognized as the best in its industry for leveraging its supply network for competitive advantage. Since we sought the "industry leader," we were constrained to conduct dyadic case studies across two industries. This two-industry design enabled us to identify common themes in building and using trust as a supply chain governance mechanism. The dyadic case studies with these focal firms and their suppliers provided insight into five elements of trust construction.

Context Matters. Context shapes trust construction. At the beginning of each interview, we asked supply managers to define trust and to discuss the level of trust that exists in their industry. As part of this discussion, we asked managers to evaluate the level of trust in their "typical" customer relationship on a 10-point scale (1=No Trust; 10=Complete Trust). We asked them to explain why they gave the rating they did. The follow-up question asked managers to rate the focal customer on the same 10-point question. The discussion generated by these questions disclosed that managerial perceptions evolve on a comparative basis. That is, rather than speaking in absolute terms, managers often say, "We trust Company A more than our other customers."

For example, in the retail setting (Case #1), the typical customer relationship scored a 6.57. The focal retailer obtained a 7.90 ($p<.05$) trust score. Supply managers noted that the industry is intensely competitive, operates on low margins, and that trust is rare. Despite this characterization, many managers described the focal company as not just their best partner but also as a company that can be trusted—at least more so than any other customer. By contrast, in the service-provision setting (Case #2), the typical relationship scored a 6.9 compared to a 9.11 ($p<.01$) for the focal service provider. Supply managers described a "kinder, gentler" industry that yielded much higher profit margins. Within this context, they consistently noted that the focal firm is "easily the most trusted customer in the industry." Importantly, a small number of interviewed suppliers worked with both focal firms (albeit the account managers were different). Account managers for the service provider claimed to be aware that the retail focal company had a strong, trustworthy reputation within their organization. Even so, they noted they were grateful their industry was not as brutally competitive as the one their colleagues had to deal with.

Beyond industry/competitive context, the interviews revealed that managers are fully cognizant of the fact that not all relationships are created equal. Simply put, relational context matters. Supply managers are intuitively aware that the type and amount of trust developed is contingent on the prospect to use trust to build distinctive capabilities; that is, as a governance mechanism. Buyer/supplier relationships that offer little value co-creation potential receive minimal investments in trust. Further, managers at "B" and "C" suppliers realize they do not possess the resources to merit stronger ties and greater investment. Managers do, however, expect to be treated with respect and want their companies to receive fair treatment. Finally, supply managers for both focal firms implied that their customers left some value co-creation opportunities unexplored. They argued that buyers should more frequently ask, “Could enhanced trust and intense collaboration improve operating and strategic performance?”

Trust is Culturally Embedded. Managers indicated that the propensity to cultivate trust is culturally embedded. In both cases studies (retail and service provision), managers explained that doing business with the focal firm is different from working with other customers. They described not just a “different feel” but also a different process and a different outcome. For example, one key differential outcome is an enhanced supplier willingness to share both information and resources and to go “out of their way to help the focal company achieve its goals.” They expressed the fact that “when the focal customer succeeds, it shares the success with us.” As a result, they expressed the idea that using trust as a governance mechanism changes the relationship in a positive way—one that opens opportunities for value co-creation. Because trust is rare, they voiced appreciation for the focal firms, saying, “We wish other customers were as good to work with.” The bottom line: Companies trust and behave in a trustworthy manner by strategic choice. In other words, both trust and collaborative business models are consciously built.

Signaling Patterns Exist. Figure 2 depicts the diagnostic scores for the trustworthiness signals that comprise performance and relationship commitment capabilities. The dark red bars are the supplier responses. Critically, certain trust signals are more readily and commonly conveyed across the two industry settings, suggesting that they may be more widely applicable regardless of industry. Specifically, in both case studies, supply managers rated the customer’s information sharing and empathy very highly. As the following brief summaries denote, both focal companies have developed sterling reputations for openly sharing information.

- Case #1 (Retailer): Supply managers noted that the level at which the retailer shares information is unprecedented and unparalleled in the industry. The retailer embeds information sharing in its process improvement and relationship management initiatives. As a result, the retailer shares more information with suppliers than the services company. However, it expects supply partners to do more with the information. One manager noted, “[the retailer] provides us the best information to manage our business.”
- Case #2 (Service Provider): Supply managers expressed appreciation for access to both operating and relational information. For instance, shared forecasts and order histories help suppliers plan capacity utilization. However, being apprised of relationship status was viewed as more important. As one manager noted: “They tell you when you are wrong; thank you when you are right.”

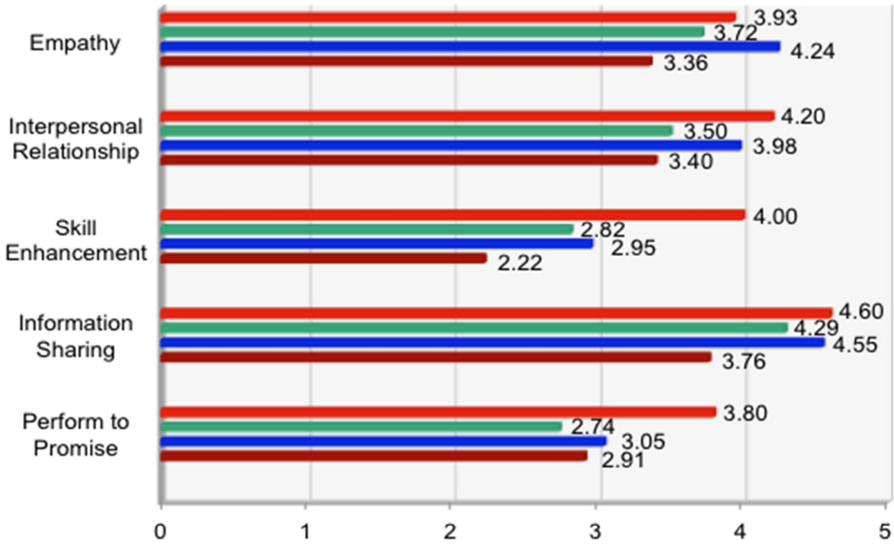
Just as some trust signals are commonly employed, others appear to be equally difficult to embrace—especially on a widespread basis. Indeed, few companies proactively invest in partner capabilities. Thus, it is not unexpected that both focal firms received relatively low average ratings on this facet of trustworthiness. However, it is important to note that both companies take a selective (i.e. contextual) approach to such investments. For instance, the retailer’s resource-sharing initiatives are quite extensive. But, they are limited to a select group of value co-creation partners. Among this group of strategic suppliers, the focal retailer received outstanding ratings for its “investments in partner skills.” Not surprisingly, these suppliers rated the focal retailer as highly trustworthy and viewed it as *the* industry’s customer of choice.

Finally, the interviews and the diagnostic results reveal that companies can rightly pursue alternative trust-construction strategies. That is, despite sharing some common trustworthiness-signaling patterns, the following summaries describe how they substantively differentiate their trust-construction strategies.

- Case #1 (Retailer): At Honda, Teruyui Maruo emphasized the importance of strong interpersonal relationships between a buyer and a sales representative, saying, “Suppliers don’t trust purchasing because purchasing means cost, but they must trust you. Suppliers must develop confidence in you. Suppliers may not trust purchasing, but you want them to trust you." The retailer lives by this creed. The result: Supply managers consistently talked about the positive relationships they had with the retailer's buyers, noting, "[The buyer] honors order commitments as well as commitments to the relationship."

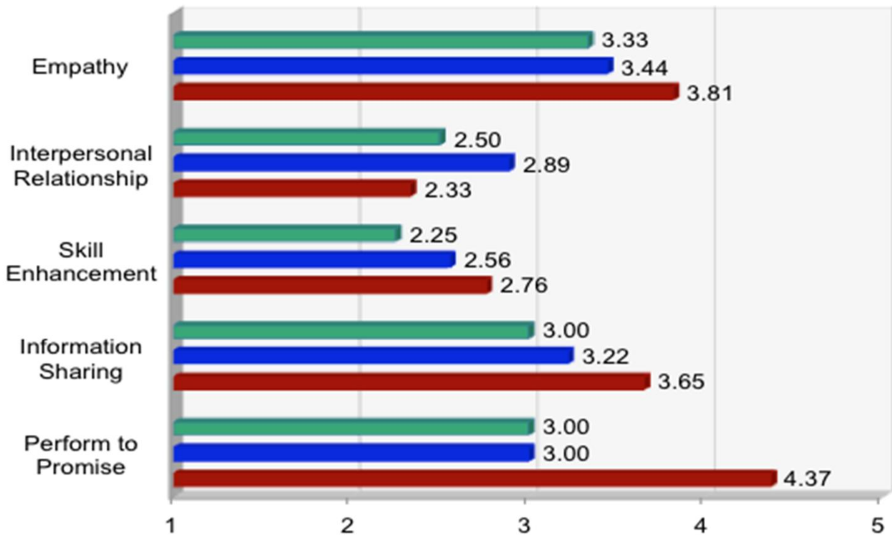
- Case #2 (Service Provider): The services company, by contrast, counts on high levels of empathy to cultivate a sense of trustworthiness. Suppliers described the service company as being "generous with their time; flexible with ideas and willing to adjust when necessary." Further, many suppliers found this service company's approach to collaboration as "refreshing," because "they treat [suppliers] with respect." By being empathetic, the services company has cultivated a reputation as a great company to do business with.

Panel 2a: Evaluations of Trustworthiness Dimensions (Retailer)[1]



[1] Kruskal-Wallis tests reveal significant (p=.05) difference in scores among groups for information sharing, skill enhancement, interpersonal relationships, and empathy.

Panel 2b: Evaluations of Trustworthiness Dimensions (Services Comany)[2]



[2]Kruskal-Wallis tests reveal significant (p=.05) difference in scores among groups for perform to promise and interpersonal relationship.

Figure 2 - Dyadic Evaluations of Trustworthiness Dimensions

Overall, context and culture influence the type of signals employed by the focal firms. Although certain signals are common (e.g., information sharing and empathy) and can be found at the core of trust construction, the two focal firms pursue distinctive signaling patterns that are appropriate to their context. Thus, the need to define and develop an “appropriate” trust strategy is critical. Rather than merely thinking about buyer/supplier relationships in terms of high or low trust, trust leaders develop different types of trust to achieve strategic goals.

Construction is Iterative. Doney and Cannon (1997) posited that managers use five processes to evaluate partner trustworthiness (see Table 3). They implicitly describe an iterative trust-construction process. The two case studies supported the idea that trust construction is not just iterative but that it is also strategic. That is, both focal companies made conscious (i.e., strategic) decisions to employ trust as a governance mechanism (see Figure 3). As such, they proactively invested in trustworthiness routines, which are comprised by performance and relationship-commitment signals.

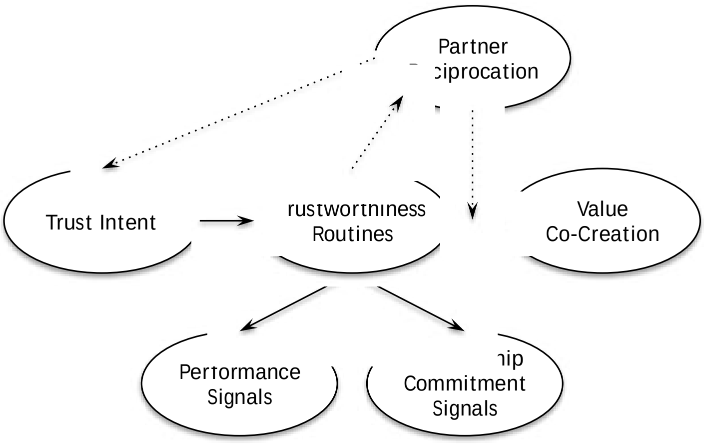


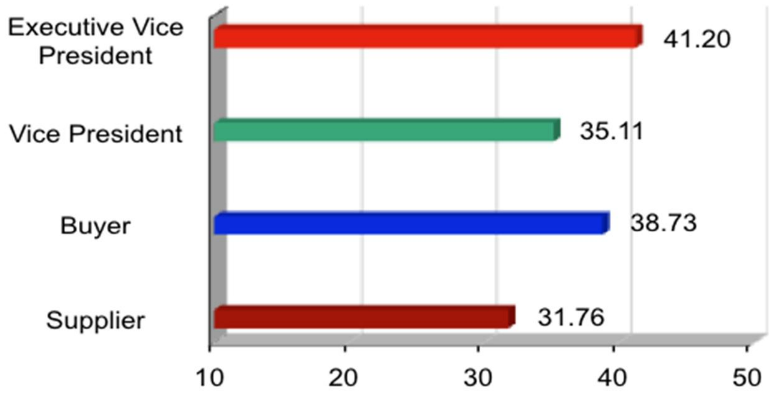
Figure 3 - An Iterative Trust Construction Process

Importantly, as the focal firms signaled trust intent through specific behaviors, supply partners assessed the nature and strength of the signals in order to decide whether and how to reciprocate. If supply partners reciprocate in a pronounced and positive way—creating confidence in the relationship and dedicating resources to specific initiatives—they enable value co-creation. Equally important, suppliers signal to the focal company their own trustworthiness as well as their desire to pursue trust-based governance. Iterative reciprocation produces a positive, virtuous cycle in which trust becomes a viable and valued governance mechanism.

Interview managers, however, noted that this iterative trust-construction process is often messy. Specifically, managers often lack awareness of what to look for as valid signals as well as how to interpret the signals they think they are observing. Further, and more difficult to resolve, signaling behaviors at both the focal firm and supply partner levels are often inconsistent across the five different signaling dimensions—perform to promise, information sharing, investing in partner skills, interpersonal relationships, and empathy. Mixed signals confuse the message, undermining proactive trust construction. Even more problematic, trustworthiness signals are sent from diverse parts of an organization. For instance, throughout the three studies, we discovered that conflicting signals often come from purchasing and accounts payable. That is, many buyers were confident that they were signaling trustworthy behavior by promising prompt supplier payment. Unfortunately, accounts payable does not always follow through. In fact, accounts payable often purposely delays payment to improve the buying firm’s cash-to-cash cycle.

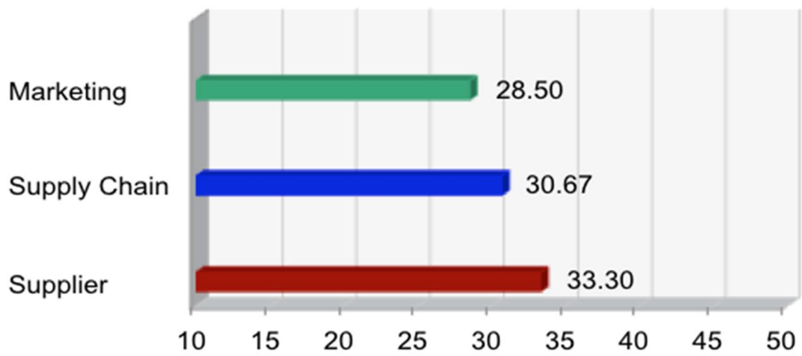
Ultimately, the target level of trust in a specific relationship—and ultimately, the desired outcome—is adjusted based on active monitoring of partner trust signals (i.e., reciprocation). That is, actual-versus-theoretical value co-creation potential and appropriateness may evolve (up or down) over time. A clearer conceptualization of what trust really is and how trustworthiness is signaled will help managers know what to look for, reducing the ambiguity and costs of trust construction.

Panel 4a: Overall Trustworthiness Score (Ratailer)[1]



[1](5 EVPs, 38 VPs, 44 Buyers, 68 Suppliers) EVP significantly higher than VP & Supplier (p=.05); VP significantly higher than supplier (p=.05); and Buyer significantly higher than supplier (p=.05)

Panel 4b: Overall Trustworthiness Score (Services Company)[1]



[1](4 Marketing, 9 Supply Chain, 63 Suppliers) Supplier trust scores significantly higher (p=.05) than buyer trust scores. No significant difference between Marketing and Supply Chain managers.

Figure 4 - Dyadic Evaluations of Buyer Trustworthiness

Positional Bias Exists. Finally, we observed perceptual bias in the trustworthiness assessments. That is, trustworthiness ratings varied significantly across buyer and supplier organizations. Significant differences also exist for vertical distance from the transaction. Importantly, bias is observed for overall trustworthiness (see Figure 4) as well as across trust dimensions (see Figure 2). Anecdotal differences were observed between functions; however, the small sample size limited significance levels. Based on the case studies, the biases exist for several reasons:

1. Asymmetrical power differentials lead buyers and suppliers to view the same behaviors differently. One supply manager, who used to be a buyer, commented, “In the past, I used practices that I now feel are unfair. I did not know what it felt like to be powerless.”
2. Cognitively, many buyers shield themselves from the thought that their behavior is aggressive. A social desirability bias leads them to view themselves as tough but fair.
3. Distance isolates senior executives from the difficulties of managing day-to-day supply relationships. Mid-tier executives tend to be the managers who arbitrate supplier complaints.
4. Familiarity with buying practices creates divergent functional views. For instance, marketers are often unaware that key investments in suppliers are being made.

Since most studies of firm-to-firm trust rely on surveys of single informants from only one side of dyadic relationships (e.g., Doney and Cannon, 1997; Johnston et al., 2004), this finding calls for a new approach to researching emotive topics like trust.

Conclusions and Contributions

Trust is vital to a collaborative approach to supply chain governance. Yet its treatment in extant literature is often unidimensional and simplistic. This study contributes to this evolving stream of discussion by undertaking three complementary in-depth qualitative studies to re-conceptualize trust in the supply chain context. Reconciling evidence uncovered in these studies with interpersonal trust underpinning extant theoretical basis, we identified two dimensions through which managers may effectively signal trustworthiness to supply chain partners: perform-to-promise capability and relationship-commitment capability. Further, the multi-informant perspective from 11 focus groups and two dyadic case studies identified specific processes and behaviors inherent in the trust-construction process. In sum, we contribute to the literature by conceptualizing both trustworthiness and its iterative construction process as a supply chain governance mechanism through a multi-informant perspective.

What is Trust? Inter-organizational trust possesses different dimensions than interpersonal trust. Whereas extant trust literature conceptualizes interpersonal trust as possessing dual dimensions of credibility and benevolence, its application as an inter-organizational governance mechanism is more nuanced. A driving factor of this difference is that while interactions are often in a personal setting, actions and consequences are instead at an organizational level. Hence, inter-organizational trust is built through behavior rather than benevolence.

Although being able to perform to promise is a basic antecedent to trust construction, moving a partnership beyond contractual governance requires repeated demonstration of the capability to commit to a relationship along many key behavioral dimensions. These include the propensity for a firm to not only share information, but also ensuring the information’s relevance and sharing them in a timely manner. Of course, not all firms possess equal innate capabilities to immediately fulfill their potential for co-creating unique values with supply chain partners. Therefore the ability to assist partnering firms with skill enhancement may further signal supply chain trustworthiness. While tangible actions are important signals in relationship commitment capabilities, intangible aspects such as mutual respect and empathy are also vital for properly contextualizing tangible actions. Because investment toward facilitating information sharing and skill enhancement may be pricey (Ravichandran and Liu, 2013), the ability for representatives from partnering firms to express understanding help to convey their importance. In other words, it’s not what you say but how you say it that matters.

In sum, trust as a supply chain governance mechanism is a multi-dimensional construct that is composed of an intricate system of behaviors signaling both performance capabilities and relational commitment capabilities. Specific behaviors belie each dimension to collectively determine the construction of a trust-based inter-organizational linkage.

How to Build Trust? The actual construction process of trust as a supply chain governance mechanism involves iterative signaling and follow-through. However, in order for the trust construction process to be both initiated and consistently in motion, most firms must overcome challenges in both firm-wide buy-in and acquiring know-how. Whereas the former dictates resource dedication toward trust construction, the latter determines the ability for firms to both recognize trust signals from partners and formulate appropriate responses in return.

Successfully overcoming the above challenges may empower firms to begin an intricate iterative process of signal-recognition and signal-transmission to build trust. First, firms must recognize both the competitive and strategic context under which their partnerships take place. Competitive intensity serves as an industry boundary condition to trust construction. Therefore, trust signals sent by a firm should be considered relative to all its competitors in an industry. On the other hand, costs involved in developing deep collaboration through investing in both information linkage and mutual skill enhancement naturally limits such activities only with those relationships deemed as strategic. Second, how deep trust is culturally embedded in an organization determines its ability to recognize trust signals and formulate appropriate transmission in return. Firms that wish to gain the know-how must make a concerted effort to consciously build trust into their daily operations and all facets of their processes, including the willingness to share both risks and rewards with their partners.

With proper resources and cultural support, firms may build trust through an iterative process of both tangible actions and intangible attitudes. This iterative process includes not only meeting mutually-determined goals but also proactively investing in dyadic interface with both information and capabilities. Once established, trust requires continuous maintenance and nurturing in order to prevent its erosion through actions such as preserving continuity at the personal level, ensuring proper training, and ongoing timely delivery of relevant information.

Finally, not all linkages are long term. Those linkages are frequently transactional in nature and serve as a modular component of a firm's supply chain. However, this is not to say that trust is any less important for even short-term linkages. Firms that take a competence-driven approach to building transactional trust frequently leverage their existing knowledge and processes to ensure that transactions are conducted in the most efficient manner possible to maximize potential value creation. On the other hand, firms with a culturally-embedded, empathy-driven approach to building trust emphasize mutual satisfaction in order to ensure an overall harmonious transaction from beginning to end.

Altogether, the three complementary studies show that trust as a supply chain governance mechanism depends on both the intended degree of engagement with suppliers as well as the relationship-commitment capabilities of the focal firm. For signaling trustworthiness, costs are sometimes difficult to justify. Therefore, behaviors and actions associated with collaborative trust and are used strictly with strategic suppliers. Used well, such signals change the relationship's value-creation ability. Of note, although the retailer's relationships are less harmonious than those of the services company, its emphasis on higher levels of value co-creation appears to provide greater inimitability.

Key differences also exist between interpersonal trust and trust as a supply chain governance mechanism. Interpersonal trust rests upon credibility and benevolence. While credibility may be reasonably analogous to perform-to-promise capability, trust built on relationship-commitment capabilities instead of benevolence avoids the "dark side" of trust—being susceptible to opportunistic or complacent behavior. A capabilities perspective sets high expectations and requires constant assessment.

Researching Trust. The current study explored trust as a supply chain governance mechanism through three complementary and in-depth qualitative studies. While interviews are conducted in a one-on-one setting, the additional information uncovered through focus groups and dyadic case studies show that not only is trust a multifaceted governance mechanism, but different levels and types of trust exist; yet, most trust constructs are unidimensional, consisting of relatively few items. More robust, nuanced measures are needed to understand how companies can proactively develop the right type and level of trust to achieved desired outcomes. Further, evaluation of buyer trustworthiness (Figure 2) shows that perception bias influences how managers assess trust and its influence on relationship quality and value-creation. To accurately understand trust dynamics, more multi-informant, dyadic research designs are needed.

Ultimately, our exploratory case studies reveal that although empathy contributes to trust development, companies do not need to be “friends” to benefit from trust-enabled collaboration. Further, the results reveal that any company can build trust if managers possess the resolve to make the investments to consistently signal trustworthiness. Yet, as Honda’s Dave Nelson, noted, “Many [companies] simply don’t have the heart for this sort of thing.” The question thus arises, “Can capabilities-based trust enable differential performance?” Researchers need to provide the nuanced insight to help decision makers make the right assessment.

References available upon request

SHAPING OPERATIONS STRATEGIES FOR SOCIAL ENTERPRISES: DIRECTIONS FOR FUTURE RESEARCH

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Abstract

Social enterprises are ambidextrous organizations that conduct commercial activities in simultaneous with the pursuit of social goals, running operations to meet social needs of their target beneficiaries. This hybrid operational nature raises new questions about the priorities and the decisions involved in the specification of their operations strategy. This paper develops a research agenda for the development of knowledge on the specification and pursuit of an operations strategy for hybrid enterprises, building on operations management literature and on illustrations form the existing practices of social enterprises.

Keywords: Operations strategy, Social enterprises.

Introduction

Operations strategy is a well-explored and mature topic in Operations Management (OM) literature. In the exhaustive historical analysis of articles conducted by Rungtusanatham et al. (2003), operations strategy ranks in the top five research foci. The specification of an operations strategy involves a set of managerial decisions concerning the structure and functioning of the production system. Hence, a given production configuration is one amongst other existing alternatives, that, in a specific moment and decision making context, is perceived as superior for improving production effectiveness, in order to meet market requirements and to serve the pursuit of competitive advantage. The overall business strategy of the organization naturally plays a key role in shaping the operations choices (Lowson, 2002; Slack et al., 2001), once operations are an essential component for the functioning of an organization. Several authors emphasize the role of operations strategy on performance (Díaz Garrido et al., 2007; Espino-Rodriguez and Gil-Padilla, 2014; Martín-Peña and Díaz-Garrido, 2008).

The proliferation of hybrid organizations that has been taking place in the competitive landscape in recent years (Walker, 2015) is likely to challenge the prevalent knowledge on operations strategy, as it raises a set of interrogations about the goals that the operations function must respond to in such contexts, as well as about the nature of the operations decisions involved. Hybrid models are being adopted by a particular type of organizations, labelled as social enterprises, whose operations address social and economic concerns at once, for which they conduct commercial activities simultaneously with other activities to pursuit their social mission.

Social enterprises are attracting a growing interest from academics and practitioners (Doherty et al., 2014). Their growth has been explained to a great extent by the economic setting that has been fueled by the economic crisis, notably in the European context, and that has resulted in substantial shortenings in the financial support provided by the State to non-profit organizations that typically addressed social needs (e.g. elderly care, social inclusion, etc.).In the current context the financial sustainability of the organizations addressing such beneficiaries is put at risk, pushing them to find alternative ways to generate revenues while pursuing their social mission (Battilana and Lee, 2014; Smith et al., 2013).

Social enterprises face many challenges once they try to conciliate social and economic concerns in the same extent. They have many specificities when compared with traditional companies. Unlike traditional for-profit organizations, social enterprises do not pursue a competitive advantage in order to overcome their competitors. According to Glavas and Mish (2014), those organizations aim to become more responsive ecologically and socially while prospering economically, they focus on collaborative advantage once most of them strive to have resources that are sustainable and therefore imitable, commonly found and substitutable. This is a necessary condition to assure that the model is scalable and easily replicable in other contexts.

To be successful, social enterprises need to do a great job managing limited resources, for which, naturally, the attainment of effective operations management must be at the core of their priorities. Notwithstanding, the majority of the studies addressing the management of social enterprises to this date has been focused on the definition and characterization of their goals and activities, and notably marked by the proliferation of arguments about their specificities, whereas the development of new managerial knowledge in this domain remains largely unaddressed.

However, there are enough arguments to sustain that it is important to develop knowledge about the functional and operational organization of these enterprises, notably from the perspective of their operations management. The ambidextrous nature of their operations, i.e. running commercial and non-commercial activities raises new questions about how to characterize the operations strategies adopted by social enterprises. The present paper provides a first building block to address this question, building on the literature and reasoning derived from the practices of social enterprises acting in the field, proposing a research agenda with the main topics that claim for further research efforts.

This paper is organized as follows: the next section reviews the main principles and concepts that support the development of an operations strategy; then a characterization of the hybrid nature and operations of social enterprises is laid down. After that, the paper presents a discussion building on the literature and the existing social enterprise practices, putting forward four directions for future research, emerging from the identification of some specificities of social enterprises for which there are no answers in the literature yet. A conclusion section is also offered.

The main concepts behind an operations strategy

Operations strategy is an important domain within the operations management literature. Slack et al. (2001) define operations strategy as “the pattern of strategic decisions and actions which set the role, objectives and activities of operations’. These decisions tend to be of medium-to long term, as they involve the commitment of resources, and can be classified as structural and infrastructural. Structural decisions have strategic implications, require significant investment and have a long-term impact. They include decisions regarding some aspects such as the manufacturing process technology, the vertical integration degree, facilities and plant location. On the other hand, infrastructural decisions have short-term impact, they do not require large investments and are related to operational practices and decisions, such as the planning and control systems, organizational structure, workforce management and quality management (Díaz Garrido et al., 2007; Espino-Rodriguez and Gil-Padilla, 2014). Strategic decisions in services are very similar to the structural and infrastructural decisions presented in the literature on the manufacturing field (Espino-Rodriguez and Gil-Padilla, 2014; Roth and Menor, 2003). However, in the context of services, structural decisions also include those related to the touch points with clients, such as the relative allocation of service tasks to the front- and back-office and number and types of distribution channels (Roth and Menor, 2003).

Structural and infrastructural decisions represent how the enterprise uses its resources and technologies to reach a sustainable competitive advantage in its sector (Lowson, 2002), such as cost, quality or flexibility and to obtain the expected performance (Espino-Rodriguez & Gil-Padilla 2014; Díaz Garrido et al. 2007; Martín-Peña & Díaz-Garrido 2008). Figure 1 illustrates the relationship between operations strategy, competitive advantages and performance.

Four different perspectives can be used to define an operations strategy, each one of them poses different questions to managers. The first one is the top-down perspective that derives from the organizations' business strategy to define the operations strategy. Then, there is the bottom-up perspective, in which operations strategy emerges from the day-to-day experience, the actions and decisions taken within operations. The third perspective identified is the market requirements perspective which is developed according to the requirements of the organization's market position. Finally, the operations resources perspective suggests the definition of an operations strategy based in the operations resources available (Slack et al., 2001).

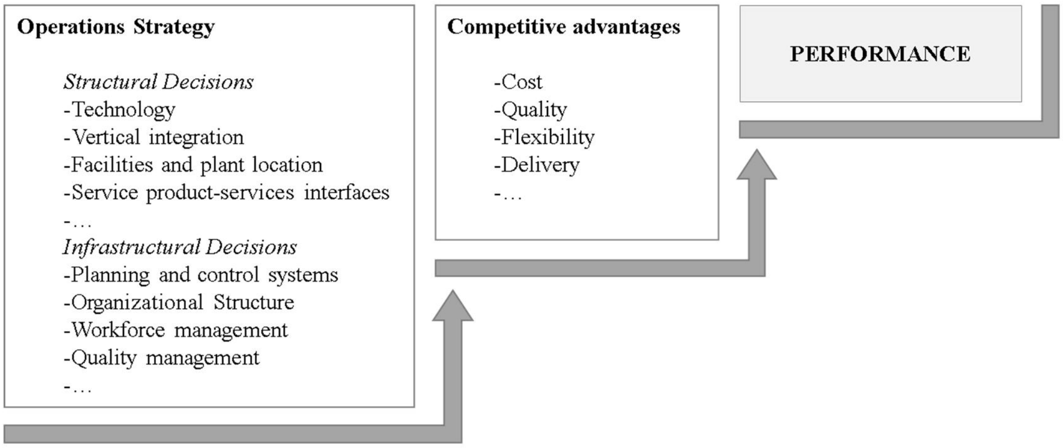

Figure 1 – An overview to operations strategy in manufacturing
(Source: elaborated by the author based on Slack et al. (2001))

The definition of competitive advantages to pursue is the starting point to establish an operations strategy. According to a literature review conducted on typologies and taxonomies of operations strategy, three generic operations strategies for industrial companies are commonly accepted in the literature:

1) strategies aiming to minimise costs;
2) strategies focusing on the highest quality products and also trying to adapt to customer's needs;
3) strategies of organisations that implant new technologies and new operations processes with great flexibility as a way to differentiate.

The same authors also identify one additional operations strategy in which organizations combine a set of operations competitive priorities in order to obtain competitive advantages (Martín-Peña and Díaz-Garrido, 2008). However, it is recommended for organizations to focus on only one strategic priority (cost, quality, flexibility, etc.) because they require different operational structures and infrastructures and therefore different strategic decisions should be taken for each case. An enterprise focused on low costs hardly is able to deliver high quality products or distinctive products that fill all the requirements of their customers. The competitive advantage pusued by an organization may change over the different stages of development (Boyer and Lewis, 2002). In addition to cost, quality and flexibility, delivery is frequently mentioned in the literature as one of the main competitive advantages that are preferentially chosen by manufacturing companies (Boyer and Lewis, 2002; Díaz Garrido et al., 2007; Espino-Rodriguez and Gil-Padilla, 2014; Martín-Peña and Díaz-Garrido, 2008). From a manufacturing point-of-view, delivery relates to provide fast deliveries, meet delivery promises or reduce production lead time (Boyer, 1998).

These competitive advantages (cost, quality, flexibility and delivery) are often mentioned in research works on services. However, authors such as Ibrahim (2010) and Phusavat and

Kanchana (2008) also consider the customer-focus as well as the know-how as competitive advantages pursued by services companies.

In the next section are introduced the social enterprises as hybrid organizations and presented the main challenges faced in the definition of an operations strategy arising from their hybrid nature.

An introduction to social enterprises as hybrid organizations

Social enterprises are a particular type of organization with social and economic concerns, i.e. organizations that pursue a social mission while engaging in commercial activities (Battilana and Lee, 2014; Pache and Santos, 2012). Social enterprises are considered hybrid organizations once they often incorporate characteristics from the private and social sector (Ebrahim et al., 2014; Jäger and Schröer, 2013; Pache and Santos, 2012; Smith et al., 2013; Wilson and Post, 2011). Some authors consider that social enterprises may also incorporate characteristics from the public sector and civil society (Brandsen and Karré, 2011; Doherty et al., 2014).

In the organizational landscape they are positioned between traditional non-profit and traditional for-profit organizations (Neck et al., 2009; Wilson and Post, 2011). There is a wide range of hybrid business models in this spectrum. Social enterprises may adopt different legal forms according to the existing legal frameworks in their country. For example, in Portugal social enterprises do not exist legally, leading this type of organizations to act as associations, cooperatives or commercial enterprises. Regardless the legal form they adopt, what distinguishes social enterprises from other organizations are the principles they follow. According the authors' understanding, social enterprises should have a social mission clearly defined and carry out commercial activities that should generate a great part of their revenues. Profits, if they exist, should be reinvested to scale the social impact. Battilana et al. (2012) define the hybrid ideal as a fully integrated organization. Everything the enterprise does produces both social value and commercial revenue. Mission and profit aims are integrated in the same strategy. However, a key challenge for hybrid organizations is how to conciliate the management of operations associated to the activities that aim to generate social value, which often don't generate (enough) revenues, with other activities with a more commercial nature.

The separation between commercial and social activities may lead to a high risk of mission drift (Ebrahim et al., 2014; Santos et al., 2015) and to some ambidexterity in the domain of operations management. Examples of potential operational challenges include the need to deliver products or services to actors with very different requirements and expectations about the organization (i.e. beneficiaries from social activities vs. customers for the commercial activities) and the need to effectively manage human resources with very heterogeneous capabilities and motivations (e.g. volunteers vs. employees). This ambiguity may be more or less evident, varying according to the degree of integration of the two types of activities. For example, SPEAK is a linguistic and cultural service offer whose objective is to bring people of different nationalities together and thus contribute to the social inclusion of migrants in the cities where they are living. Anyone can apply to learn or teach any language or culture including those of the country where they are residing. Teachers work in a volunteer basis. At the same time, there is the SPEAK PRO program that provide specialized services to individuals and enterprises. Revenues generated through the SPEAK PRO program are used to ensure the financial sustainability and social impact of SPEAK. In this case, social and income generating activities are run separately, they are independent from each other. On other hand, in organizations like Vintage For A Cause both types of activities are related. Vintage For A Cause is a sewing club, where women with over 50 years without professional occupation transform used clothes mainly donated by others in vintage inspired clothes, with an exclusive design and supported by professional stylists. The clothes are sold in the online shop and in some stores in the city and all the profit is used to ensure the project's sustainability.

Overall, social enterprises have many specificities when compared with traditional companies. Unlike traditional for-profit organizations, social enterprises do not seek valuable, rare, inimitable and non-substitutable resources in order to ensure a competitive advantage and overcome their competitors. Most of them strive to have resources that are sustainable and therefore imitable, commonly found and substitutable (Glavas and Mish, 2014). This is a necessary condition to assure that the model is scalable and easily replicable in other contexts, perhaps by other individuals or organizations. Most important than reach a competitive advantage, they focus on collaborative advantage. Their processes are transparent and they collaborate with others in the value chain, in their sector and also from different sectors.

The literature on social enterprises published in the last years has essentially focused on the definition of their boundaries in the organizational landscape, notably by discussing what distinguishes social enterprises from pure non-profit and for-profit organizations, in order to identify the main tensions arising from their hybrid nature. However, some questions remain unanswered regarding the strategies adopted by social enterprises in terms of operations management. There are evidences that point to the existence of differences which represent opportunities for future research. In the next section, are presented four topics that claim for more research.

Social enterprises: what is different regarding their operations strategy?

The existence of a wide variety of social enterprises make believe there are significant differences between them (and in relation to other types of organizations) in the way they organize their operations once they propose solutions in different domains (e.g. environment, health, poverty, etc.) and aim to achieve different levels of social impact. For example, Smith and Stevens (2010) suggest the existence of three types of social entrepreneurship. The first one focus on local concerns and the developed solutions are often rather small in scale and scope. The second type of social entrepreneurship identified by them deals with issues that are relevant to local concerns but the solution may be replicable in other different contexts. The last one focus on large-scale issues. Social entrepreneurs aim to create social enterprises that provide solutions able to replace those currently provided by the existing institutions.

Based on some evidences from the field, are identified four topics to be explored in future research efforts regarding some aspects related to the specificities of social enterprises in terms of operations management and the definition of their operations strategy: 1) ambidexterity of operations; 2) goals of operations strategy; 3) structural and infrastructural decisions; and 4) the strategic role of operations in social enterprises over time.

Research topic 1: Ambidexterity of operations in social enterprises

As already mentioned previously, the hybrid nature of social enterprises leads to several challenges in terms of operations management. It is expected that according to the level of integration between social and income generating activities, social enterprises can assume different approaches. Unlike the hybrid ideal, as described by Battilana et al. (2012), empirical evidences point to the fact that social enterprises with a less integrated approach may define different operations strategies for the different domains of action, the social and the commercial. Once again, the case of SPEAK can be used to illustrate this. In this social enterprise can be distinguished two separate structures - SPEAK and SPEAK PRO - both essential for the mission accomplishment. The first because it represents the operationalization of the mission itself, the last due to its extreme importance to the financial sustainability of the enterprise.

The same happens with ColorADD, although it presents a different level of integration of their social and commercial activities. This social enterprise has developed a colour identification system aiming to make communication for colour-blind more efficient and inclusive through a licensing system for using the codes in the development of products and signs. At the same time, ColorADD promotes education activities in schools as a way for children get aware of colourblindness and teach them how to use the code that is already available in several products and services through the licencing system. Both activities are important to the success of the enterprise, but probably they require different strategies due to their distinct nature and target-groups.

Examples like SPEAK and ColorADD challenge the existent knowledge on operations management and make believe that some social enterprises should adopt more than one operations strategy, with different goals, make different operations decisions, and perhaps use different resources. This might be the best option to ensure that they are effective in their action and that nor the social concerns neither the commercial concerns are undervalued.

However, this is an assumption which must be confirmed by further research. In what extent social enterprises define different operations strategies for different activities? To what extent makes sense set up different operations strategies? Are social enterprises adopting separated social and commercial operations more successful than those with more integrated approaches? How should social enterprises organize their operations to avoid the risk of mission drift? Understand more deeply how social enterprises organize their operations facing this ambidexterity will be important to advance the knowledge in the field and help practitioners to deal with it, support them in the decision-making process regarding the definition of the operations strategy and contribute to reduce the risk of mission drift.

The next research topic to be explored is the definition of goals to achieve with the operations strategy.

Research topic 2: Goals of operations strategy

In the context of for-profit organizations, operations decisions are a mean to achieve a competitive advantage that should be aligned with organizational goals. However, it is clear in the literature that the main focus of social enterprises is to propose a solution to a social problem that is at least economically sustainable and preferentially replicable. They do not intend to have the highest market quote or overcome the competition, but increase their social impact and at best mitigate the social problem or need they are trying to solve (Trivedi and Stokols, 2011).

Therefore, the idea that social enterprises are competing in the market by low costs or quality, would be limited. The goals of social enterprises are much more ambitious, from the "social" point-of-view, than competitive advantages reported in the literature on operations strategy in manufacturing and services. Those competitive advantages would not fit at all social enterprises. Perhaps, in some cases, they can be used to characterize the commercial activities, when they are separate from the social activities. Doctor Gummy is a startup that sells sweets gluten and lactose-free and without artificial colourings or preservatives. The idea was born to be applied to the pharmaceutical industry, even before the enterprise sell their products to food distribution, once any child does not like medicines but loves sweets. Thus, a chemical engineer decided to add to sweets, the active principle of medicines in order to facilitate administering of medications to children. When Doctor Gummy is dealing with food distribution companies, it is competing with others by the quality of its products that have distinctive characteristics, as was mentioned previously. The same is applicable to SPEAK PRO that is sold as a high quality service, provided by specialized staff.

Once competitive advantages are usually connected to performance goals, reviewing the literature on performance measurement in social enterprises can be a good start to understand which goals social enterprises are pursuing. In this domain and according to Luke et al. (2013) a recurring theme is the building or reinforcement of the sense of community. For example, the mission of SPEAK is help to solve the problem of social exclusion of migrants and contribute to their integration in the cities where they live through a program of linguistic and cultural knowledge sharing, breaking language barriers and bring people from different backgrounds together. In this case, perhaps it makes sense to talk about the community engagement or a collaborative engagement as a goal to achieve. This supports the idea of Glavas and Mish (2014) that these organizations pursue a collaborative advantage instead a competitive advantage.

There remain research opportunities to identify what are the most common goals of social enterprises when they define their operations strategy. What are the main advantages social enterprises pursue? Do social enterprises tend to adopt a competitive or a collaborative approach? Next, will be discussed another topic related to the structural and infrastructural decisions made in order to implement an operations strategy.

Research topic 3: Structural and infrastructural decisions in social enterprises

Social enterprises, likewise pure for-profit organizations, should make some strategic design choices when defining their operations management strategy according to their goals and priorities. This includes some decisions with an impact in the long-term, often related to physical assets of the social enterprise such as facilities and the points of contact with stakeholders, for example the beneficiaries. Some social enterprises like SPEAK and Vintage For A Cause involve their beneficiaries as co-producers and co-creators of the solution they deliver. In the same extent, when the social enterprise cannot have their own resources, it may establish partnerships to incorporate external resources in their delivery system of the solution, using facilities owned by other entities like the city council, as happen in the case of Vintage For A Cause, or even involving volunteers in the process as a way to reduce costs with staff (Doherty et al., 2014; Fazzi, 2012).

On the other hand, there are the decisions with an impact in the short-term. The hybrid nature of social enterprises leads to several internal and external tensions arising from the desire to generate social impact and meet market demands at the same time. In the last years, several authors have identified some critical domains for social enterprises to balance social and commercial goals that may have an impact on operations management and operations decisions. Doherty et al. (2014) suggest two operational mechanisms to manage these tensions. The first is to use the social mission as a force for strategic direction and the second mechanism consists in finding the optimum conditions to successfully link the generation of revenues to the creation of social value. In this article, are suggested three main critical domains for strategic operations decision in social enterprises based on the tensions that have been identified in the literature: governance, human resources management and performance measurement.

Social enterprises may adopt different strategies in terms of governance. If they are acting in more than one location, they can chose if they want to involve local actors in the decision making as experts on local issues or make decisions centrally (e.g. at the national level) and give to experts the legitimacy to address the organizational and strategic challenges of the social enterprise (Pache and Santos, 2012). For example, SPEAK acts at the community level, probably some local actors are included in its governance model and involved in decisions at the local level, in addition to their involvement in the delivery of the solution.

The human resources management is another area of tension for social enterprises. According to the level of integration between social and commercial activities, managers may choose by a distinct workforce to social and commercial activities or a workforce able to perform both. In less integrated social enterprises, it is expected to find a structure composed by people with "social" background to perform social activities and people with commercial expertise allocated to commercial activities (Battilana and Lee, 2014; Doherty et al., 2014). They may also opt by a more or less specialized staff, involving more or less volunteers (Battilana and Lee, 2014; Doherty et al., 2014; Pache and Santos, 2012). For example, teachers in the SPEAK program working directly with the beneficiaries of this social enterprise are volunteers but those working for the SPEAK PRO program are high qualified people. Social enterprises with a more integrated approach are likely to have a workforce that combines skills from both sectors. Once this is a new field and it is difficult to find human resources with a "hybrid" profile, there are some authors suggesting that social enterprises searching for employees with this profile may hire people with no work experience and provide them training in order to have a staff aligned with the dual concerns of the organization (Battilana and Lee, 2014).

Finally, it is important to establish metrics for the performance monitoring and identification of opportunities to the continuous improvement of operations. This could be specially challenging in social enterprises because social indicators have distinct characteristics when compared with financial indicators. Social activities usually have a long-term impact, difficult to measure with quantitative metrics (Ebrahim et al., 2014; Smith et al., 2013).

Therefore, many questions remain without answer regarding the specificities of social enterprises in terms of structural and infrastructural decisions: Are the beneficiaries involved in the process as co-creators or co-producers or are they not involved in the delivery of the solution to the social problem? What is the level of involvement of local actors in the governance of the social enterprise? Does the social enterprise prefer to have human resources with a social or commercial background or both? Will the social enterprise give preference to social or financial indicators?

Next, will be presented the last research opportunity identified, regarding the change of the strategic role of operations in social enterprises over time and how it can differ from other organizations.

Research topic 4: The strategic role of operations in social enterprises over time

Operations tend to assume different roles over time according to the maturity level of the enterprise. A four-stage model of the strategic role of operations was proposed by Hayes and Wheelwright in 1984 and is commonly accepted in the literature, used as a reference model in manufacturing and services (Lillis and Sweeney, 2013; Slack et al., 2001). The model suggests that the operations function evolves from an initial stage where it is internally neutral, going through intermediate stages, to the last stage where it is labelled as externally supportive. In the first stage, the operations function is internally focused, reactive and works to correct the worst problems. During the implementation of the strategy in the second stage, are conducted efforts in order to adopt best practices and the enterprise intends to be as good as their competitors. After that, in the third stage the operations function seeks to support the organizations' business strategy with the purpose of the enterprise becomes the best in its industry. Ideally, in the fourth and last stage, operations are the basis of competitive advantage for the organization, redefining industry expectations and setting the standard in this industry (Slack et al., 2001).

Social enterprises, like other enterprises, develop and grow over time and their needs change throughout their life cycle. Therefore, they are also expected changes in the strategic role of operations. Social enterprises must be very similar to other enterprises in the first stage. Their operations function is mainly reactive and only tries to correct the worst problems. However, as time passes, social enterprises do not aim to become the best in their industry, once they are trying to solve a social problem that was not answered before, at least in the same context they are acting. Competition is not a major concern for social enterprises and probably the four-stage model proposed by Hayes and Wheelwright should be rethought and adapted to these new business models. How does the role of operations evolve over time in social enterprises? How could be adapted the last stages of the four-stage model to fit the specificities of social enterprises? New empirical research should be conducted in order to collect evidences on the roles that operations assume in social enterprises according to the stage of development where they are.

Figure 2 summarizes the four research topics discussed previously, highlighting the study of the ambidexterity and goals of operations as key components in the definition of an operations strategy and, on the other hand, the acknowledging of structural and infrastructural decisions as well as the strategic role of operations over time as important aspects for the implementation of that strategy.

Conclusion

In the last years, have emerged new business models that combine characteristics of two or more sectors towards the adoption of hybrid structures. Social enterprises are a particular case of hybrid organizations that pursue social objectives while conducting income generating activities. This paper aimed to explore the main specificities of social enterprises regarding de definition of an operations strategy, pointing some directions for future research.

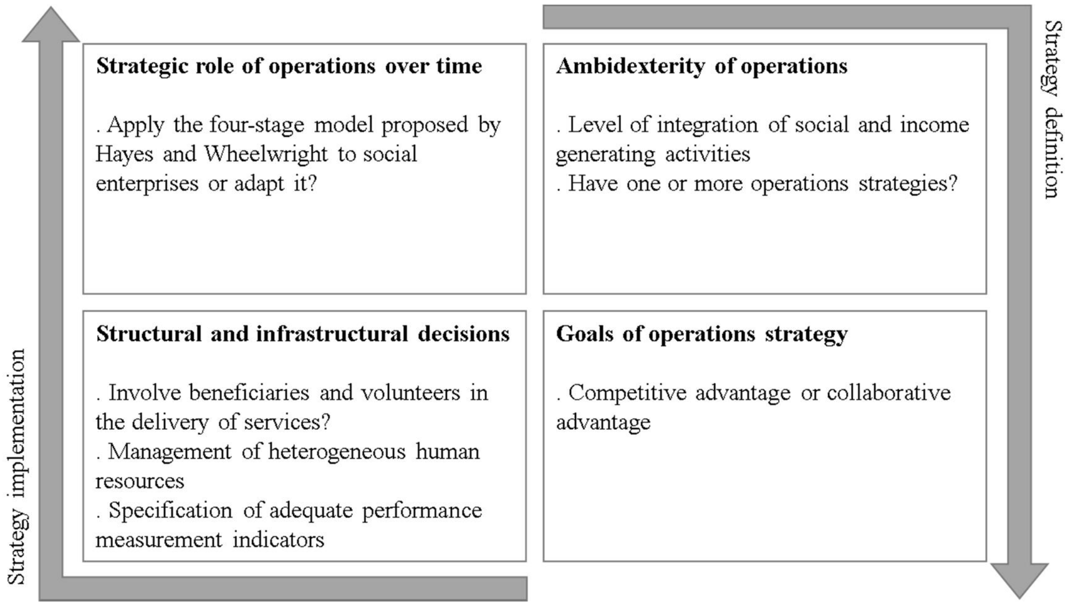

Figure 2 – Directions for future research on operations strategy of social enterprises (Source: elaborated by the authors)

When compared with pure for-profit organizations, social enterprises face many challenges arising from their hybrid nature that should be reflected in their operations strategy, notably in terms of goals, decisions and the ambidexterity of operations. First, more research is needed in order to identify which are the main operations decisions made in terms of governance (involve local actors vs. give to experts the legitimacy to decision making), human resources (a distinct workforce for social and commercial activities vs. a workforce able to perform both), and performance measurement (balance between social and financial indicators). Second, it is important to study what kind of goals are pursued by social enterprises regarding their operations strategy and that are behind structural and infrastructural decisions, investigate if social enterprises are mainly focused in achieving a competitive advantage or if, on the other hand, they are more focused on a collaborative advantage. Third, further research should be conducted to deeply understand how social enterprises organize their operations, dealing with the distinct nature of their activities. Finally, a last direction for future research was identified concerning the study of the strategic role of operations over time.

The wide variety of social enterprises in terms of social problems addressed and the level of integration of social and income generating activities make believe that there is many research opportunities in this field in order to translate and adapt what is the existing knowledge in the operations management literature to these new business models emerging in the organizational landscape. In a first instance, exploratory work should be conducted recurring to qualitative data (e.g. case studies), once this is an unexplored field. However, due to the great variety of social enterprises, it is believed that future research will evolve to quantitative data collection methods (e.g. surveys) that allows the study of larger samples and the generalization of the results. In this paper were pointed some directions for future research that may help researchers to identify new opportunities to advance knowledge in this field.

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MEASURING SUSTAINABILITY – NETWORK SCIENCE BASED ANALYSIS OF WATER RESOURCES MODELS

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Abstract

Water resources are crucial factors of global sustainability and momentous elements of every complex system interacting with subsystems like population dynamics, communities, pollution, agriculture, economic growth, energy. To understand these interactions, detailed local, regional and global models are constructed to represent the whole ecosystem. In these complex systems, there are many variables, and they are strongly interdependent. This makes it difficult to know exactly which inputs contribute to an observed output, and what state variables should be controlled or observed to get a controllable and observable dynamical system. To answer these questions we represent the causal loop diagrams of these models as complex networks to identify model elements with the strongest impact on controllability and observability. We demonstrate the applicability of the method on six water related models. The results show that the method is able to evaluate the impact of water related state variables into the dynamical behavior of complex ecosystems.

Keywords: sustainability, dynamical systems, controllability, observability, network

Introduction

The future availability and quality of water are among the most critical factors of global sustainability. Up to the millennium, each year four million children died from diseases related to water (Simonovic, 2002). In 2010, this reduced to 1.8 million (Corcoran, 2010). In 2000, in developing countries 1.1 billion and 2.4 billion people suffer from the lack of safe drinking water and appropriate sanitation, respectively (WHO, 2000). During the first decade, these numbers decreased to 900 million and 2.6 billion (Corcoran, 2010). “Clean water and sanitation” and “Life below water” are two of the 17 global Sustainable Development Goals identified by the UN. The 2016 UN World Water Development Report states that three out of four jobs are water dependent. Floods and droughts as well as water availability impact livelihoods of over one billion people directly in the agricultural sector (UN World Water Development Report, 2016). Water resources are crucial elements of every complex system, interacting with population dynamics, social and political processes, pollution, agriculture, economic growth, energy, and every other represented subsystems.

Changes in any of these subsystems have major impacts on the water resources but quantitative and qualitative changes of water resources have significant impact on our quality of life and our environmental well-being.

Because the variables in a complex ecosystem are so strongly interdependent, changes to system inputs can have unintended, unanticipated consequences. This makes it difficult to know exactly which inputs contribute to an observed output, and the extent of each factor's contributions. Our goal is to better understand these interactions by the structural analysis of dynamical models.

The key idea is that to identify state variables that have central role in controllability and observability of complex ecosystems, we represent the causal loop diagrams of the models as networks (Liu, et al., 2011) and analyze these networks using our NOCAD analytical toolbox (Abonyi, 2016).

To demonstrate the applicability of this approach we selected a few local, regional and global models. The results show that this type of analysis can highlight the effect of the water related state variables in complex ecosystems, so we hope that this approach can open new possibilities to support decision making related to sustainable water management.

In the following, the second session presents the studied sustainability models. In the third section we introduce the concepts of applied network science based methodology. Finally, we present the preliminary results and suggestions for further refinement of our approach.

Networks science based analysis of causal loop diagrams of complex systems

Complex systems are often represented by causal loop diagrams. The key idea of our work is that in case of dynamical systems these diagrams define networks of the state variables which network represents the structure of the state transition matrices of state space models (see Figure 1).

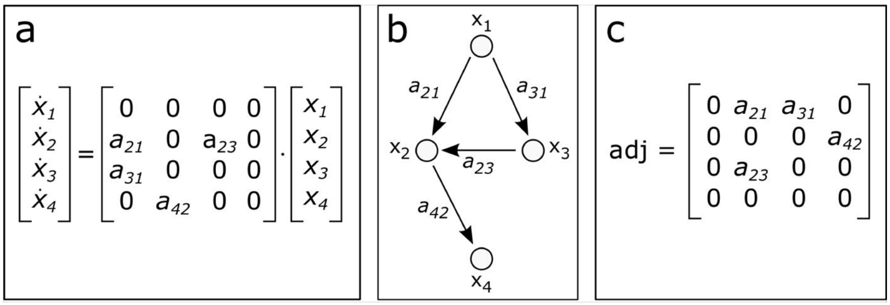

Figure 1 – Representations of a state transition matrix. (a) Illustrative state equation with four state variables without inputs and outputs. (b) Network representation of the dynamical system. (c) The adjacency matrix of the network (b) is the transpose of the state-transition matrix in (a).

From this viewpoint causal loop diagrams are interpreted as a structural representation of linear time-variant state-space models, which contains the state equation (equation (1)) and the output equation (equation (2))

$$\dot{x}(t) = \mathbf{A}(t)x(t) + \mathbf{B}(t)u(t), \tag{1}$$

$$y(t) = \mathbf{C}(t)x + \mathbf{D}(t)u, \tag{2}$$

where x stands for internal state variables, u represents the inputs, i.e. the external actuators, and y is the vector of outputs, i.e. the external sensors of the system. Matrices **A** and **B** define how state variables and inputs influence the state variables, while matrices **C** and **D** define how state variables and inputs influence the outputs, respectively.

Controllability and observability properties of dynamical systems

The two most important properties of dynamical systems are controllability and observability. A system is controllable if we can drive it from any initial state to any desired final state within finite time with properly selected inputs (Cameron & Hangos, 2001). To determine the controllability, we have to create the controllability matrix

$$\mathcal{C} = [\mathbf{B}, \mathbf{AB}, \dots, \mathbf{A}^{N-1}\mathbf{B}], \tag{3}$$

where **A** is the state transition matrix, and **B** describes the input matrix according to equation (1). The system is controllable if the Kalman's criterion is satisfied, i.e. the rank of controllability matrix is equal with the number of state variables, $rank(\mathcal{C}) = N$ (Kalman, 1963).

A system is observable if we can determine the state of the system at any given time by a finite set of measured records of input and output variables (Cameron & Hangos, 2001). To ascertain if a system is observable, we have to create the observability matrix

$$\mathcal{O} = \begin{bmatrix} \mathbf{C} \\ \mathbf{CA} \\ \vdots \\ \mathbf{CA}^{N-1} \end{bmatrix}, \tag{4}$$

where **A** is the state-transition matrix, and **C** describes how outputs observe state variables, according to equation (2). Like controllability, the system is observable, if the rank of observability matrix is equal with the number of state variables, $rank(\mathcal{O}) = N$.

Representing dynamical systems as networks eventuate networks with significantly large sizes. Determining appropriate **B** matrix for controllability or appropriate **C** matrix for observability is a challenging task to a given **A** matrix. In 2011, Liu et al. proposed the maximum matching algorithm to solve the challenging task that provide those nodes, which should get an input (Liu, et al., 2011); and those, where we have to place an output (Liu, et al., 2013) to create a controllable and observable system. These nodes are named as driver and sensor nodes, respectively.

The maximum matching algorithm

The maximum matching algorithm is a combinatorial method which creates the largest disjoint edge set in a graph. Although the maximum matching is interpreted on undirected graphs, it is interpretable in directed network as well (Figure 2) (Liu, et al., 2011). The disjoint condition in directed network means that two edges cannot have common starting or ending point. Usually, more sets of edges can satisfy the disjoint condition with the same size, so the result of the maximum matching is not unique. As a result an edge is matched if it is in the disjoint edge set, otherwise it is unmatched. A node is matched, if it is an ending point of a matched edge, otherwise it is unmatched. If a matching returns all nodes as matched nodes in the network, then it is called as perfect matching.

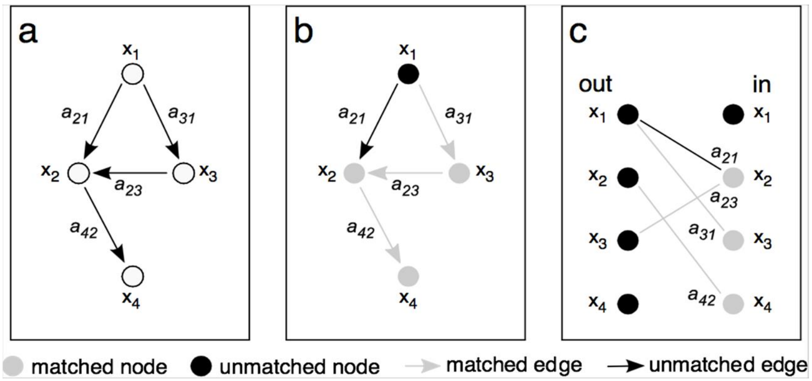

Figure 2 – Maximum matching in directed networks. (a) A simple, unweighted directed graph with 4 nodes and 4 edges. (b) The result of maximum matching in the directed network. Edge $\boldsymbol{a_{21}}$ cannot be a member of the disjoint set of edges, as it has common starting point with $\boldsymbol{a_{31}}$ and common ending point with $\boldsymbol{a_{23}}$. Ending points of matched edges are matched nodes. (c) Undirected representation of the directed network. For each node in directed network there are two nodes in undirected representation, one for outgoing edges and one for incoming edges. The representation of edges is obvious. The result of maximum matching is the same in directed and undirected representations.

The unmatched nodes of the network, which are associated to state transition matrix $\mathbf{A}$, are the driver nodes. If we transpose the network, i.e. change the direction of edges, then the generated unmatched nodes are the sensor nodes for the same system. With these driver and sensor nodes the system will be controllable and observable. Since the maximum matching algorithm generally does not provide a unique solution, the provided driver and sensor nodes can be different for the same topology. The methodology accepts all of these solutions as a result and does not evaluate them by other aspects. With this approach we determined the main sectors that put pressure on sustainability, and those, that can indicate the changes well.

Measures of node centrality

Beside the controllability and observability based analysis we applied network based centrality measures to characterize sectors in the models, namely the in degree, out degree, node betweenness, PageRank, control and observe centrality. With in- and out-degree we determined the number of neighbors of a given sector and established those, which have the ability to influence (maximum of out degree) or observe (maximum of in degree) many other sectors. The node betweenness associates a number for each node based on how many geodesic paths are going through the given node (Freeman, 1977). Sectors with high node betweenness are sensitive to the changing of other sectors. The PageRank measure could show that which state is the most visited in the system if we suppose that random walks, or Markov-chains, are allowed (Page, et al., 1999).

With PageRank, we determined the most central sectors in the models if we suppose that the sectors can affect each other with small possibility despite there is no edge between them. Control centrality determines how many state variables can be controlled directly by an input (Liu, et al., 2012). It differs from how many state variables get the signal of the input, which means a simple reachability. The control centrality is a subset of the reachable state variables. Observer centrality is determined in a similar manner.

Note on the applicability of the approach

Since the result of maximum matching is not unique, we were able to highlight the role of water related variables by generating the disjoint edge sets in a way as these variables have more "willingness" to be selected as unmatched (controller or observer) nodes.

To calculate this problem-specific matching and the previously presented measures of node centrality we developed a NOCAD MATLAB toolbox that can be downloaded from the website of the authors (Abonyi, 2016).

We have to note that the causal-loop representation assumes that although the system is complex and nonlinear, the structure of the problem is time-invariant. Since the presented control and observation centralities are calculated using the structural instead of the numerical rank, in some cases one additional controlled or observed states could be selected.

We assume that the structural analysis of the **A** state transition matrix gives valuable feedback for experts interested in the qualitative analysis of the model and design of the intervention points and measurements required to monitor or control of complex ecological systems.

Results and discussions

In this session we study six causal loop diagrams to cover a wide spectrum of local and global models of water resources. In the following, we introduce these models and present their most important network related measures (the detailed results are presented in the Appendix).

ANEMI 2

The first version of ANEMI model was introduced in 2010 as an integrated description of climate and global change (Davies & Simonovic, 2010). The model contains eight components: climate, carbon cycle, economy, land-use, population, natural hydrological cycle, water use, and water quality systems. ANEMI 2 provides an improved representation of the carbon cycle and climate system (Akhtar, 2011). The main components of this version are climate, carbon cycle, land-use, population, food production, hydrologic cycle, water demand, water quality, and energy economy (Figure 3).

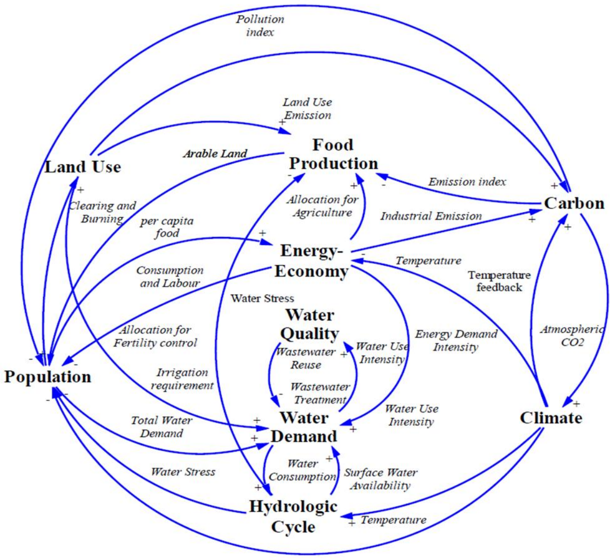

Figure 3 – Structure of ANEMI 2 model

The model contains 9 nodes and 24 edges. The network is sufficiently dense, allowing for controlling and observing only one driver and one sensor nodes (theoretically). To highlight the role of water, we selected the *Water Quality* sector as driver and sensor node. The *Climate* sector has the maximum out degree, so climate possesses an influential role in the model. The *Water Demand* sector has the maximum in-degree. The PageRank emphasizes the central role of *Water Demand* in the global sustainability. The change in any other sector is connected to changes of water demand. Population has the maximum node-betweenness value, so *Population* is a main sector that usually part of geodesic paths, thus this sector react early on changes

Haveli canal in Pakistan

The model of Inam et al. integrates water management scenarios to model the problem how to increase surface water availability and decrease marginal quality groundwater (Inam, et al., 2014). The model is applied for the Haveli canal circle in Rechna Doab basin in Pakistan. With the model, they want to influence the salinity of soil, which mainly depends on the quality of irrigation water. The related causal loop diagram can be seen in Figure 4.

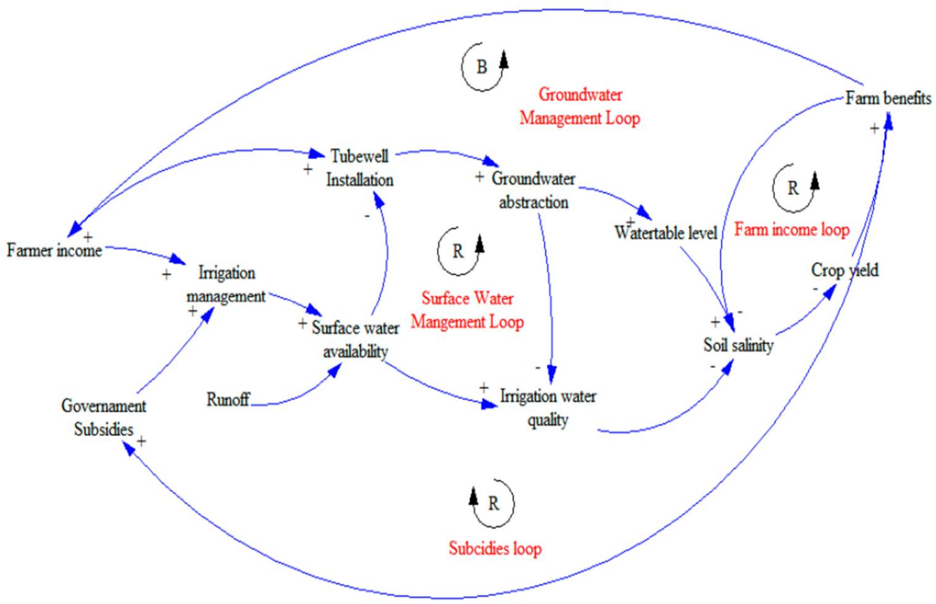

Figure 4 – Causal loop diagram of Haveli canal problem

The model contains 12 nodes and 17 edges. Two driver and two controller nodes are required to ensure controllability and observability of the system. *Farm Benefits* has the highest out-degree, as the investments mainly depend on farms.

The *Soil Salinity* has the highest in-degree, node-betweenness and PageRank. The model concentrates on *Soil Salinity*, so the results of in-degree, node-betweenness and PageRank are understandable since soil salinity depends on good quality irrigation.

In the following, we enumerate the driver and sensor nodes, and in brackets we note how many nodes are influenced by the driver or sensor nodes. The determined driver nodes are *Government Subsides* (11 nodes) and *Runoff* (12 nodes). *Runoff* cannot be controlled, but it is visible, and beside *Farm Benefits*, *Government Subsides* it is important in investments. The determined sensor nodes are *Irrigation Management* (12 nodes) and *Irrigation Water Quality* (12 nodes). These nodes regulate mostly the *Soil salinity*.

Hydrology subsystem of northern New Mexico

Fernald et al. studied the traditional irrigation communities in southwestern United States where land use conversion, water scarcity, ecosystem and cultural changes threaten the life and traditions (Fernald, et al., 2012). Climate change and population growth change the agricultural and rural communities of New Mexico significantly. Although these communities were able to overcome most of the challenges, their future is still uncertain. The purpose of this study is to identify adaption strategies to ensure the sustainability of these communities. The causal loop diagram of the hydrology subsystem of the study can be seen in Figure 5.

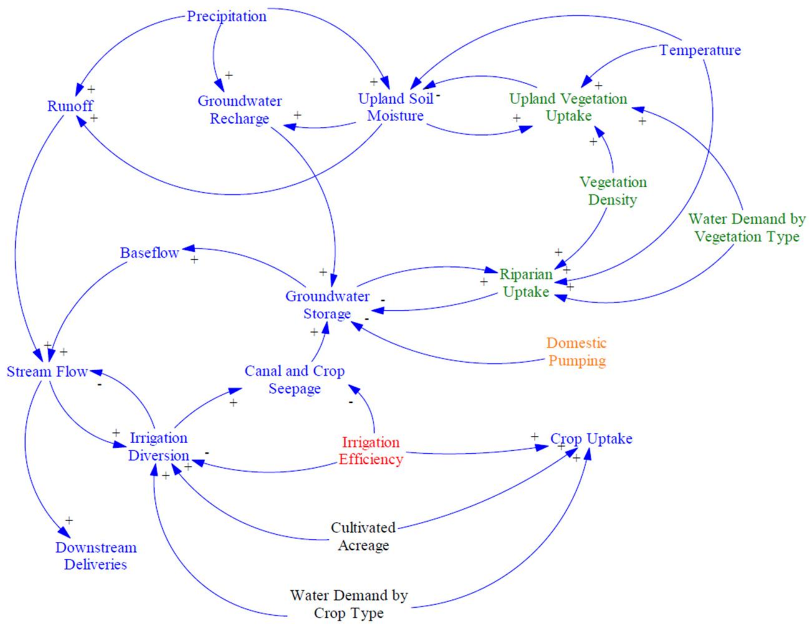

Figure 5 – Causal loop diagram of Hydrology subsystem in New Mexico

The model contains 20 nodes and 33 edges. To ensure controllability and observability 8 driver and 8 sensor nodes are required. It is understandable that *Precipitation* has the highest out-degree. The maximum in-degree, node-betweenness and PageRank belongs to the *Groundwater Storage* sector. It is not trivial, that with this result we can determine that, *Groundwater Storage* sector is an extremely important sector for the hydrology subsystem. The driver nodes are *Precipitation* (12 nodes), *Temperature* (12 nodes), *Water Demand by Vegetation Type* (12 nodes), *Domestic Pumping* (8 nodes), *Irrigation Efficienc*y (9 nodes), *Cultivated Acreage* (9 nodes), *Water Demand by Crop Type* (9 nodes) and *Vegetation Density* (12 nodes), while the sensor nodes are *Groundwater Recharge* (7 nodes), *Downstream Deliveries* (19 nodes), *Baseflow* (18 nodes), *Canal and Crop Seepage* (18 nodes), *Water Demand by Vegetation Type* (1 node), *Domestic Pumping* (1 node), *Water Demand by Crop Type* (1 node) and *Crop Uptake* (2 nodes). This example deals only with the amount of necessary water but demonstrate well the amount of factors influencing water reachability. The model also specifies small but important elements that are important from the viewpoint of water resources, such as *Precipitation* and *Temperature*.

Kenya's water crisis

In Kenya, nearly 18 million citizens faced with the lack of access to safe and clean water. Stakeholders were analyzed to determine their effects on the phenomenon (ISAT380E, 2013). The four main stakeholders are *Agribusiness*, *Subsistence Farmers*, *Government* and *Non Profit Organizations*. The effects of these stakeholders on water related areas were expounded, and with these connections a causal loop diagram was established that can be seen in Figure 6.

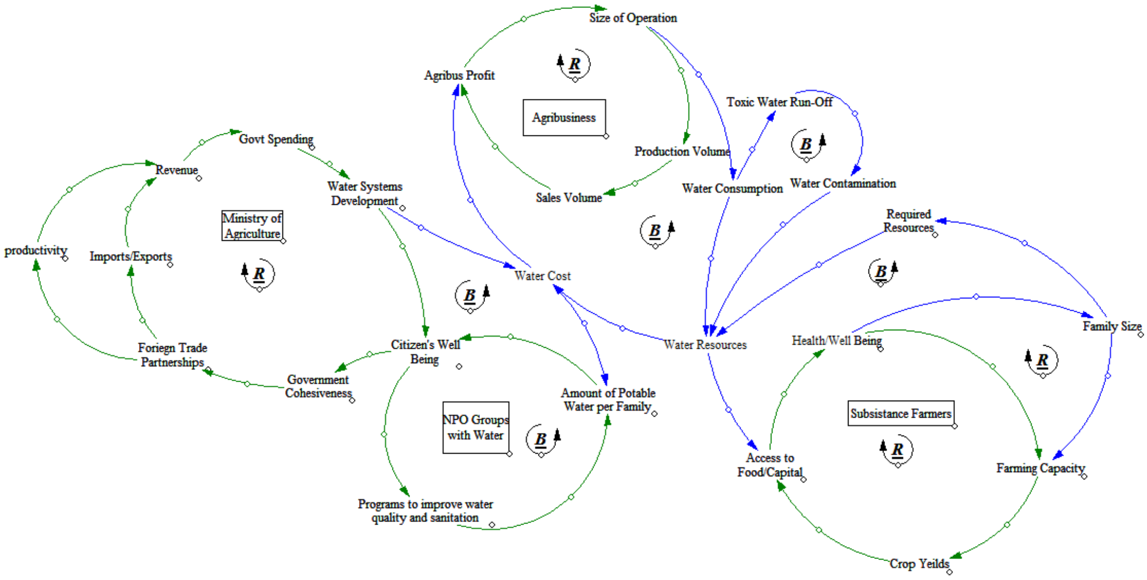

Figure 6 – Causal loop diagram of stakeholders' interactions in Kenya

The network of stakeholders contains 25 nodes and 34 edges. Four driver and four sensor nodes were necessary to control and observe the system.

The maximum out-degree belongs to *Water Systems Development*. The highest in-degree belongs to *Water Resources*. *Water Cost* has the maximum node-betweenness, and *Citizens Well Being* has the maximum PageRank value. These four factors describe the interrelations of human water usage. The *Cost of water* directly influences most of the sectors. *Citizens Well Being* is the most influenced sector.

The determined driver nodes are *Programs to Improve Water Quality* and *Sanitation* (25 nodes), *Water Consumption* (25 nodes), *Imports/Exports* (25 nodes) and *Required Resources* (25 nodes), while the sensor nodes are *Water Cost* (25 nodes), *Imports/Exports* (25 nodes), *Water Resources* (25 nodes) and *Water Contamination* (25 nodes). In case of this model, the network related centrality measures were proven as the most applicable and reflect the fact that while the water resources might be more available on other continents, the processes are universal, and water plays a central role everywhere.

The effects of urbanization

Since 1990 the percentage of urban living increased from 10% to 55%. Grimm et al. wanted to determine the effects of cities on global change (Grimm, et al., 2008). Their work discusses how the urban areas impact the environment. The model contains five subsystems: *changes in land-use*, *biogeochemical cycles*, *climate change*, *hydrosystems*, and *biodiversity*. Grimm et al. also determined that expanding of *urban areas* affects not just the *rural land*, but cause resources exhaustion, waste and problems in quality of water resources. The causal loop diagram of the hypothesis of Grimm et al. can be seen in Figure 7 (Elmasry, 2015).

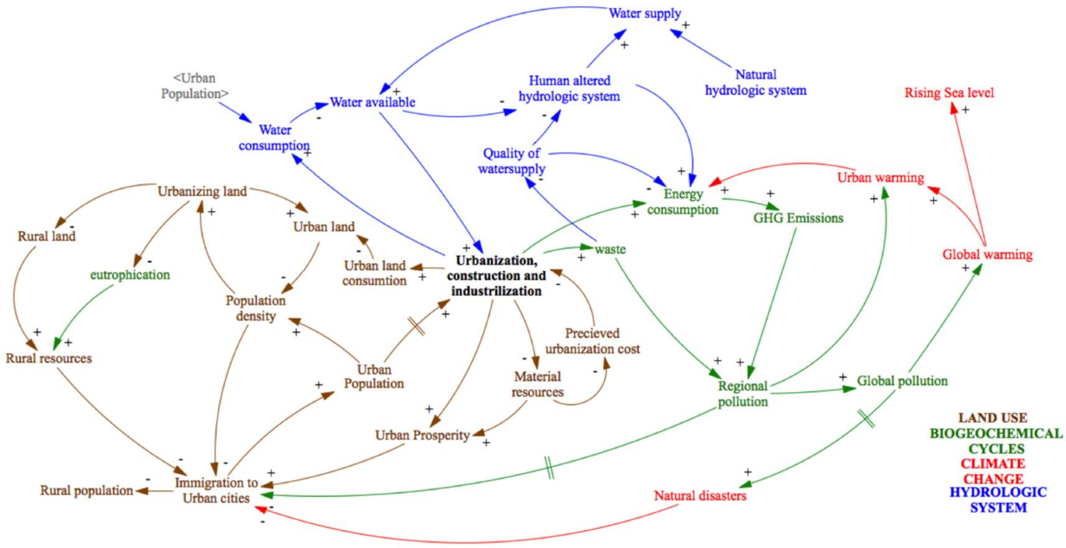

Figure 7 – Causal loop diagram of the hypothesis of Grimm et al.

The model consists of 30 nodes and 47 edges. Because of the relatively few connections, the number of necessary inputs and outputs are 9, respectively. *Urbanization*, *Construction* and *Industrialization* have the maximum out-degree and maximum node-betweenness values. Since the central element of the model is the *Urbanization* it is understandable that development of this sector has highest influence on other sectors. *Immigration to Urban Cities* has the maximum in-degree and maximum PageRank. These results reflect that the model built around urbanization, i.e. the most influential element is immigration. The Driver nodes are Urban Population 1 (29 nodes), Material Resources (28 nodes), Perceived Urbanization Cost (28 nodes), Rural Population (1 node), Natural Disasters (28 nodes), Rising Sea Level (1 node), Urban Land Consumption (28 nodes), Rural Land (28 nodes) and Natural Hydrologic System (29 nodes), while sensor nodes are Water Available (28 nodes), Water Supply (28 nodes), Rural Population (29 nodes), Natural Disasters (28 nodes), Rising Sea Level (29 nodes), Urban Land (28 nodes), Rural Land (28 nodes), Rural Resources (28 nodes) and Natural Hydrologic System (1 node). From driver nodes only Rising Sea Level and Natural Hydrologic System, but from sensor nodes Water Available, Water Supply, Rising Sea Level and Natural Hydrology System are also water related important sectors. This shows well that the change of urbanization significantly affects all water related sectors.

WorldWater model

The WorldWater model is the extension of famous World3 model (Meadows, et al., 2004). The World3 model contains five sectors, namely*: population, agriculture, economy, nonrenewable resources* and *persistent pollution.* These sectors were extended by water resource sectors: *water quantity* and *quality* (Simonovic, 2002). The two new sectors contain multiple feedback links with each other, and the rest of the model. Simonovic noted that on global level water pollution will be the most important water issue. The two aims of the research were to highlight the importance of the strong feedback between human economy and water availability, and the identification of global water issues. The causal loop diagram of the model can be seen in Figure 8.

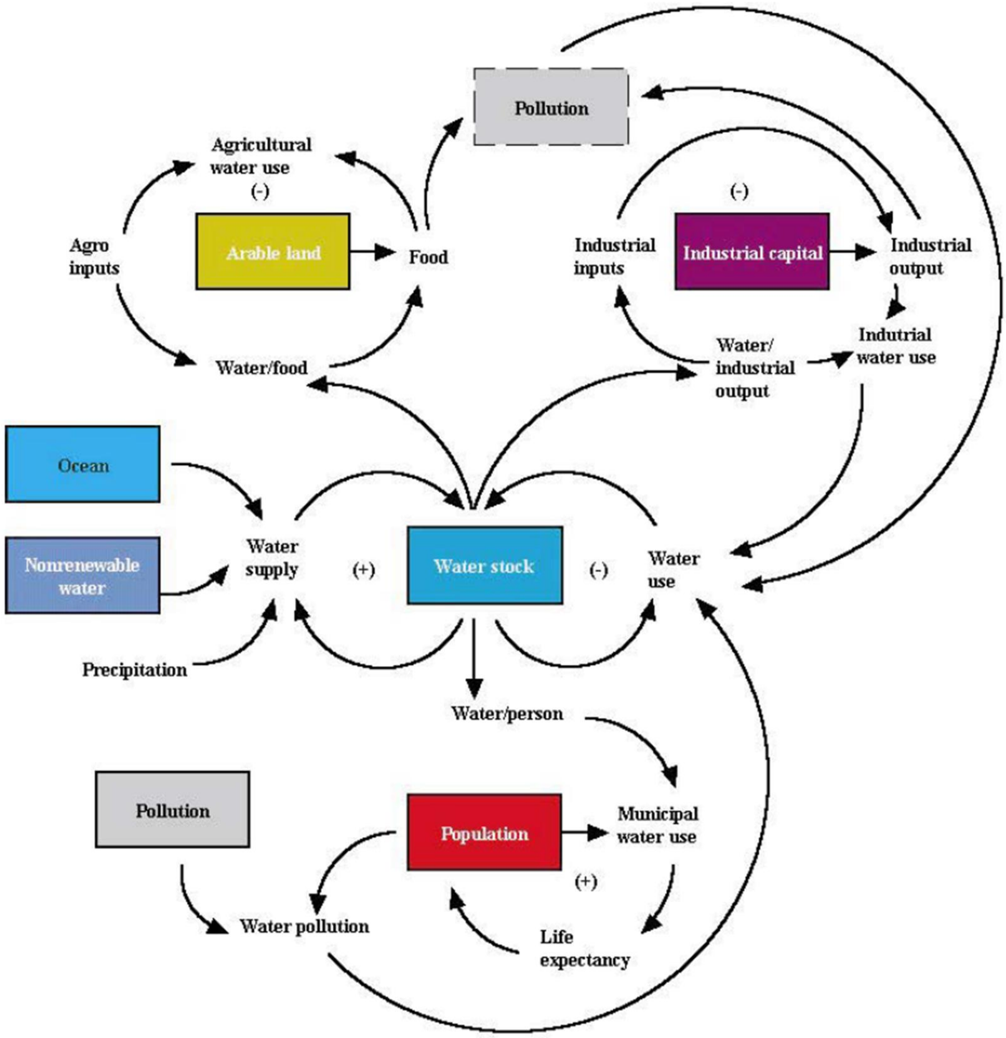

Figure 8– Causal loop diagram of WorldWater model

The model contains 23 nodes and 31 edges. 9 driver nodes and 9 sensor nodes were necessary for controlling and observing the behavior of the model. *Water Stock* has the highest out-degree, node-betweenness and PageRank. The maximum in-degree belongs to *Water Use*. These results are new and unexpected as besides the other components, water related sectors are identified as structurally important parts of the model. The necessary driver nodes were Water/person (16 nodes), Agricultural water use (1 node), Pollution 2 (17 nodes), Ocean (17 nodes), Nonrenewable water (17 nodes), Precipitation (17 nodes), Agro inputs (17 nodes), Arable land (17 nodes) and Industrial capital (17 nodes), the sensor nodes were Water use (22 nodes), Industrial water use (22 nodes), Agricultural water use (23 nodes), Water pollution (22 nodes). Other sectors have only one node each. (Pollution 2, Ocean, Nonrenewable water, Arable land and Industrial capital). Determined driver nodes do not suggest that water related sectors would be more important than others, but sensor nodes from 6 of the 9 sectors are related to water. This could be tentatively interpreted that based on this model, if we want to change water related sectors are similar to other fields, but changes are more visible on these sectors.

Conclusions

Drawing conclusions and making decisions based on complex causal loop diagrams are challenging due to the complexity of connections and unpredictable influence of feedback loops. In order to gain this potential new insight from these models, we developed a network science based approach and a MATLAB toolbox for the analysis of these models. Using our methods, we can determine the most important state variables and the critical intervention and measurement points. We studied published, well-known dynamical models of water resources to demonstrate the applicability of the methodology.

Water related state variables were shown as important parts of every model. Results from specialized, local models highlighted that, the struggle for quality water is the most critical problem. The comparative analysis of these models provides also suggestions for model improvement and development.

The developed methodology and tool are also applicable in other fields of model based analysis of complex systems, so it can be used as a general decision support tool.

Appendix

In Table A1 results of models *ANEMI version 2* and *Haveli canal circle in Pakistan* are shown. Following the name of driver and sensor nodes in the parenthesis the first value represents the control or observer centrality, i.e. how many nodes are influenced or observed by the driver or the sensor node. The second value shows how many state variables are influenced or observed in the system by the driver or the sensor node in percentage.

Table A2 – Results of models ANEMI version 2 and Haveli canal circle in Pakistan

Name	ANEMI version 2	Haveli canal circle in Pakistan
Number of nodes	9	12
Number of edges	24	17
Number of driver nodes	1	2
Number of sensor nodes	1	2
Maximum out degree	Climate	Farm Benefits
Maximum in degree	Water Demand	Soil salinity
Maximum node betweenness	Population	Soil salinity
Maximum PageRank	Water Demand	Soil salinity
	drivers:	drivers:
	Water Quality (9 node(s); 100%)	Government Subsides (11 node(s); 91.6667%)
	sensors:	Runoff (12 node(s); 100%)
	Water Quality (9 node(s); 100%)	sensors:
		Irrigation Management (12 node(s); 100%)
		Irrigation Water Quality (12 node(s); 100%)

In Table A2 the results related to the *Hydrology subsystem of northern New Mexico* and *Stakeholders of Kenya's water crisis* models are presented.

Table A3 – Results of models Hydrology subsystem of northern New Mexico and Stakeholders of Kenya's water crisis

Name	Hydrology subsystem of northern New Mexico	Stakeholders of Kenya's water crisis
Number of nodes	20	25
Number of edges	33	34
Number of driver nodes	8	4
Number of sensor nodes	8	4
Maximum out degree	Precipitation	Water Systems Development
Maximum in degree	Groundwater Storage	Water Resources
Maximum node betweenness	Groundwater Storage	Water Cost
Maximum PageRank	Groundwater Storage	Citizens Well Being
	drivers:	drivers:
	Precipitation (12 node(s); 60%)	Programs to Improve Water Quality

	and Sanitation (25 node(s); 100%)
Temperature (12 node(s); 60%)	Water Consumption (25 node(s); 100%)
Water Demand by Vegetation Type (12 node(s); 60%)	Imports/Exports (25 node(s); 100%)
Domestic Pumping (8 node(s);40%)	Required Resources (25 node(s); 100%)
Irrigation Efficiency (9 node(s); 45%)	sensors:
Cultivated Acreage (9 node(s); 45%)	Water Cost (25 node(s); 100%)
Water Demand by Crop Type (9 node(s); 45%)	Imports/Exports (25 node(s); 100%)
Vegetation Density (12 node(s); 60%)	Water Resources (25 node(s); 100%)
sensors:	Water Contamination (25 node(s); 100%)
Groundwater Recharge (7 node(s); 35%)	
Downstream Deliveries (19 node(s); 95%)	
Baseflow (18 node(s); 90%)	
Canal and Crop Seepage (18 node(s); 90%)	
Water Demand by Vegetation Type (1 node(s); 5%)	
Domestic Pumping (1 node(s); 5%)	
Water Demand by Crop Type (1 node(s); 5%)	
Crop Uptake (2 node(s); 10%)	

Finally, in Table A3 the results of *Hypothesis of Grimm et al.* and *WorldWater models* are introduced.

Table A4 – Results of models Hypothesis of Grimm et al. and WorldWater model

Name	Hypothesis of Grimm et al	WorldWater model
Number of nodes	30	23
Number of edges	47	31
Number of driver nodes	9	9
Number of sensor nodes	9	9
Maximum out degree	Urbanization, Construction and Industrilization	Water stock
Maximum in degree	Immigration to Urban Cities	Water use
Maximum node betweenness	Urbanization, Construction and Industrilization	Water stock
Maximum PageRank	Immigration to Urban Cities	Water stock

drivers:	drivers:
Urban Population 1 (29 node(s); 96.6667%)	Water/person (16 node(s); 69.5652%)
Material Resources (28 node(s); 93.3333%)	Agricultural water use (1 node(s); 4.3478%)
Precieved Urbanization Cost (28 node(s); 93.3333%)	Pollution 2 (17 node(s); 73.913%)
Rural Population (1 node(s); 3.3333%)	Ocean (17 node(s); 73.913%)
Natural Disasters (28 node(s); 93.3333%)	Nonrenewable water (17 node(s); 73.913%)
Rising Sea Level (1 node(s); 3.3333%)	Precipitation (17 node(s); 73.913%)
Urban Land Consumption (28 node(s); 93.3333%)	Agro inputs (17 node(s); 73.913%)
Rural Land (28 node(s); 93.3333%)	Arable land (17 node(s); 73.913%)
Natural Hydrologic System (29 node(s); 96.6667%)	Industrial capital (17 node(s); 73.913%)
sensors:	sensors:
Water Available (28 node(s); 93.3333%)	Water use (22 node(s); 95.6522%)
Water Supply (28 node(s); 93.3333%)	Industrial water use (22 node(s); 95.6522%)
Rural Population (29 node(s); 96.6667%)	Agricultural water use (23 node(s); 100%)
Natural Disasters (28 node(s); 93.3333%)	Water pollution (22 node(s); 95.6522%)
Rising Sea Level (29 node(s); 96.6667%)	Pollution 2 (1 node(s); 4.3478%)
Urban Land (28 node(s); 93.3333%)	Ocean (1 node(s); 4.3478%)
Rural Land (28 node(s); 93.3333%)	Nonrenewable water (1 node(s); 4.3478%)
Rural Resources (28 node(s); 93.3333%)	Arable land (1 node(s); 4.3478%)
Natural Hydrologic System (1 node(s); 3.3333%)	Industrial capital (1 node(s); 4.3478%)

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A PROPOSED FRAMEWORK FOR MANAGING ENVIRONMENTAL CAUSES AND CONSEQUENCES OF OCEAN TRAFFIC AND PORTS

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Abstract

The cumulative and in-combination effects of ocean shipping and port operations need addressing via a detailed, rigorous and holistic framework of risk assessment and risk management. This aims to protect the natural system while at the same time obtaining societal benefits from the seas. This paper proposes a conceptual framework that integrates both an ISO industry standard risk assessment and management framework (Bow-tie analysis) and the DAPSI(W)R(M) analysis supported by the ten-tenets criteria to provide guidance for all stakeholders, including industry and government, to address these issues. Water pollution stemming from maritime logistics and SCM are used to illustrate this framework.

Keywords: Ocean Pollution, Logistics and Supply Chain Management, Ten Tenets, DAPSI(W)R(M) Problem Structuring, Bow-tie Analysis

Introduction

All of industry and users of the environment have to demonstrate that their activities are environmentally sustainable and that they fulfil all relevant national and international legislation protecting the environment (Boyes and Elliott, 2014). It is axiomatic that an industry has to prove that it is not harming the environment whereas an environmental regulatory body does not have to prove that an industry is harming the environment (McLusky and Elliott 2004). In defining and tackling environmental problems and potential problems industry essentially has to perform a risk assessment and risk management approach (Cormier et al, 2013). This requires a robust and legally defensible approach irrespective of whether the activity is building a new power plant or operating a vessel in coastal waters. Once an activity has been determined as causing an environmental effect then there is the need to enable a management approach involving problem-alleviation measures. This requires a sound conceptual framework based on good science and fit-for-purpose approaches.

We introduce in this paper a conceptual framework to provide guidance for businesses and their stakeholders, including government, to address these issues. We use pollution and other environmental effects in the logistics and Supply Chain Management (SCM) of ocean lane shipping and transport in the Baltic Sea to illustrate the use of this framework.

This paper is structured as follows. First, we review the literature to consider environmental effects on water stemming from ocean lane shipping and transport and ships resident in port developments, particularly in the Baltic Sea as operative causes with certain consequences for the framework. We next define, describe and discuss the inter-linked elements underlying the framework: the ten tenets of sustainable management stakeholder consultation criteria (Barnard and Elliott, 2015), the DAPSI(W)R(M) (**D**rivers-**A**ctivities-**P**ressures-**S**tate changes-**I**mpacts (on human **W**elfare)-**R**esponses (as **M**easures)) problem structuring method (Wolanski and Elliott, 2015), and the Bow-Tie risk assessment and management analysis approach that integrates the other two elements (Cormier et al 2013). Then, we present an integrated, conceptual framework with some observations as how to it could be implemented in our example of ballast water discharges. Finally, we draw conclusions and provide suggestions for future research to further develop this concept.

Literature Review

Effects of increased logistics on the marine environment – the size of the problem

Halpern et al (2008) illustrated the degree of activities on the world's oceans and many studies have identified the large number of sea-area users (e.g. Boyes et al, 2007). Of these, shipping and its associated activities are a major concern. Tournadre (2014) analysed global ship density using altimeter data and found a dramatic fourfold increase of traffic between the early 1990s and 2014. The only region where there was a decline of traffic is located near Somalia and is related to piracy starting in 2006–2007. The distribution of growth over different ocean basins reflects the redistribution of the international trade with the largest growth in the Indian Ocean and the Western Pacific Seas.

Ocean or short-sea shipping is well-suited for the intercontinental shipment of bulk cargo, bulky goods, containers and dangerous materials such as oil and gas over large distances. Its strengths include being very economic, environmentally-friendly as regards carbon dioxide (CO_2) emissions per tonne of cargo despite bunker fuel being a particularly 'dirty' fuel, handling very large transport volumes, and operating independent of weather conditions. As a result of globalization, container trade has increased on average 5% per year over the last twenty years and is currently around 350 million twenty-foot equivalent (TEU) container movements a year. Container traffic is around 42 million TEU between Asia and Europe and 31 million TEU between Asia and North America. Interestingly, there is 45 million TEU in Intra-Asia, which likely reflects trade between Asian countries related to sub-contracting manufacturing and providing logistics services such as consolidation for other marketplace (Grant, 2012).

The cruise line sector is not as large as the cargo sector however it is estimated that 23 million passengers cruised globally in 2015. At an average of 3,000 passengers per cruise ship that means there are about 7,700 annual cruise ship movements. Annual growth in the sector over the last thirty years is just over 7.2%. As a result, many new, large cruise ships have entered the market and it was forecast that 33 new cruise ships with over 100,000 berths and an investment of US$25 billion were planned for delivery during the period 2015-2020 (F-CCA, 2016).

Finally, there are many scheduled short- and long-haul ferry services worldwide. Holthof (2016) has estimated of the number of ferries around the world as follows: 1,085 large displacement ferries plus 111 freight-only, roll on-roll-off (Ro-Ro) with a capacity exceeding 12 passengers, 222 pure freight Ro-Ro ferries with a capacity of up to 12 passengers, 1,877 lightweight fast craft - 180 with car capacity and 1,697 passenger-only fast craft. He further estimated that the global ferry market carried 2.2 billion passengers, 258 million cars and 39 million Ro-Ro trailers in 2013.

Figure 1 shows the movement of ferries in the Baltic Sea region, excluding long-haul ferry services to the North Sea countries and Spain. Ferry traffic volumes in the Baltic region in 2013 were 238 million passengers, 92 million cars and 12 million Ro-Ro trailers. We now turn to the various environmental effects that this increased movement of ships has on marine areas, i.e. ocean or short-sea shipping lanes and port developments.

Effects of increased logistics on water – environmental issues

The generally accepted major pollution and other environmental effects from ocean and short-sea shipping include CO_2 and sulphur dioxide (SO_2) emissions in ports and at sea, fuel consumption of a non-renewable resources, pollutants from ballast water, sewage and garbage discharges, space occupation that may inhibit natural ecosystem development, acidification of ocean and sea pH levels from CO_2 and SO_2 emissions (OSPAR Commission, 2009). These effects will now be discussed in more detail with reference to the specific example in the horrendogram in Figure 3. This model has been developed from a wide knowledge of the port and navigation activities and their repercussions (e.g. McLusky and Elliott, 2004).

Rigot-Muller et al. (2013) found that end-to-end logistics-related CO_2 emissions can be reduced by 16-21% through direct delivery to a UK port as opposed to transshipment via a Continental European port, i.e. cargo feeder systems. The analysis showed that for distant overseas destinations, the maritime leg represents the major contributor to CO_2 emissions in an end-to-end global supply chain. In that regard, McKinnon (2014) argued that by packing more products into containers shippers could reduce the number of container movements and related CO_2 emissions. The pressure to minimise shipping costs would also give these companies a strong incentive to maximise fill. He surveyed 34 large UK shippers and found that inbound flows into the UK were of predominantly low density products bound for retail stores that 'cubed-out' before they 'weighed-out;' i.e. 46% of respondents importing containerised freight claimed that 90-100% of containers received were 'cubed-out', i.e. to reach the volume limit of the container before reaching the weight limit. McKinnon (2014) also found that only around 40% of shippers have so far measured the 'carbon footprint' of their deep-sea container supply chains with just 6% implementing carbon-reducing initiatives. The companies surveyed also assigned a relatively low weighting to environmental criteria in ocean carrier selection. So, while many shippers have the means to influence the carbon footprint of their maritime supply chains, the survey suggested that they are not currently using them explicitly to cut CO_2 emissions.

Figure 1 –Baltic ferry Movements (Source: Holthof, 2014)

Many of the measures that the UK shippers and their ocean carriers are implementing to improve economic efficiency, most notably slow steaming, are assisting carbon mitigation efforts. Slow steaming involves reducing the speed of a ship while at sea to reduce engine load and emissions. Slow steaming was mooted by the Maersk Line as a response to the 2008 economic recession as the spot-market price Maersk Line received in late 2008 for shipping containers from Asia to Europe or North America was around US $500 below their operating costs. The relationship between ship speed and fuel consumption is non-linear and Maersk Line calculated that by redesigning their shipping schedules, using nine ships instead of eight to ensure customer volumes were handled and slowing the vessel sailing speeds from 22 knots to 20 knots, they could reduce annual fuel consumption from 9,500 to 8,000 metric tonnes (Mt) and thus also reduce carbon emissions 17% from 30,000 to 25,000 Mt of CO_2 (Grant et al, 2015).

Only a small number of UK ports actually measure and report their carbon emissions. Emissions generated by ships calling at these ports were analysed by Gibbs et al. (2014) and indicated that emissions generated by ships during their voyages between ports are of a far greater magnitude than those generated by port activities. However, 70% of shipping emissions occur within 400 km of land; thus ships contribute significant pollution in coastal communities. Shipping-related particulate matter (PM) emissions have been estimated to cause 60,000 cardiopulmonary and lung cancer deaths annually with most deaths occurring near coastlines in Europe, East Asia and South Asia (Corbett et al., 2007; Winebrake et al., 2009).

Rising concentration of CO_2 in the atmosphere results in a slow acidification of the surface ocean (Elliott et al, 2015). Anthropogenic acidification from emissions of sulphur and nitrogen oxides (SO_x, NO_x) creates acidification and eutrophication of land and freshwater ecosystems and in terms of atmospheric aerosol effects on regional and global climate, but deposition also occurs over ocean surfaces in the form of sulphuric and nitric acids. Since the late 1990s international shipping has been recognized as a significant contributor of SO_x and NO_x to the atmosphere on local, regional, and global scales. However, the problem is less significant in the Baltic Sea compared to the Pacific Ocean and elsewhere in Asia (Hassellöv et al., 2013).

Furthermore, sulphur emissions as part of overall shipping-related particulate matter emissions is a problem for ships in port. Around 18 shipping lines signed the Fair Winds Charter in 2010, which is an industry-led, voluntary, unsubsidised fuel switching programme for ocean-going vessels calling at Hong Kong. The shipping lines are using fuel of 0.5% sulphur content or less although they all switched to the cleanest type of fuel available with 0.1 % sulphur, SO_2 emissions would drop by 80%. In return, ship operators get a 50% reduction on port and navigation charges if registered vessels switch to burning low-sulphur diesel while berthed or anchored in Hong Kong. However, low sulphur diesel is about 40% more expensive than more heavily polluting marine ‘bunker’ diesel and the scheme only covers between 30 and 45% of this higher cost. Thus, while shipping companies including Maersk Line, Orient Overseas Container Line (OCCL), Mitsui OSK Lines and Hyundai Merchant Marine have registered fleets of 10-90 ships, other cost-conscious carriers have been more reticent. APL and Hanjin Shipping were among the companies that signed the Fair Winds Charter, but neither has registered any ships with the incentive scheme (Grant et al, 2015).

Such chemical discharges to the environment are defined as contamination unless they cause a biologically harmful effect, in which case they are defined as pollution (Gray and Elliott, 2009). More recently, the introduction of organisms has also been regarded as both contamination and pollution (Elliott, 2003). Hence, after almost two decades of intensified research, regulatory and political activities focussed on the prevention of harmful organisms and pathogen transfers around the world (Olenin et al., 2011). In 2004 the International Convention on the Management of Ships’ Ballast Water and Sediments was adopted to provide a common and globally uniform approach to ballast water management (BWM). However, regionally different BWM approaches have developed. However, BWE (ballast water exchange, en route) as a BWM tool is seen as an interim solution as scientific studies have proven its limited effectiveness, in addition to the fact that the water depth and distance from shore requirements as set forth in the BWM Convention cannot be met in many circumstances (David and Gollasch, 2008). One possible solution is the adoption of a Creation of Shared Value (CSV) concept whereby all stakeholders buy-in to the sustainability goals for issues such as BWM (Aravossis and Pavlopoulou (2013).

Since the 1970s, the EU has developed many Directives for controlling the harmful effects of marine activities (Boyes and Elliott 2014). These are implemented by Member States and enforced through local and national enabling legislation. For example, while a Member State has to comply with pollution control required by the EU Directives, otherwise it gets reported to the European court, controlling discharges within its environment is under national legislation such as pollution control regulations which can lead to companies being fined. Hence it is important that businesses are aware of the legislation and are complying with it.

Scharin et al (submitted) show that the multi-use Baltic Sea has cumulative effects which require a complex assessment and management system. Its enclosed nature confers a poorer ability to purify than more open systems and hence increased environmental challenges, covering larger areas and lasting a longer period. As an example, Lehmann et al. (2014) identified areas in the Baltic Sea from where potential pollution is transported to vulnerable regions. They found that in general there is higher risk of ship accidents along the shipping routes and along the approaching routes to harbours, and that the spreading of harmful atmospheric substances is mainly controlled by prevailing atmospheric conditions and wind-induced local sea surface currents. Using sophisticated high resolution numerical models, they simulated the complex current system of the Baltic Sea, and with subsequent drift modelling areas of reduced risk or high-risk areas for environmental pollution could be identified. Lehmann et al. (2014) considered that the receiving areas of fish spawning and nursery areas and tourist areas are highly-vulnerable.

Thus corporate strategic decision-making for shippers and ocean shipping lines creates challenges when it comes to sustainability in the face of thin profit margins, rising fuel and other operating costs and global economic uncertainty. However, because of environmental controls, a sustainability risk strategy is required, particularly in the shipping industry (Kun et al., 2015)

Development of a framework for analysis

Given these constraints, a company selects a framework or technique to include sustainability into its corporate strategy including the need to assess such matters as the economic viability, technological feasibility and environmentally sustainability of that strategy. Some tools and techniques currently exist, however they are focussed on discrete situations and events or are not holistically inclusive. For example, Lam and Lai (2015) used an approach that integrates Analytical Network Process (ANP) and Quality Function Deployment (QFD) to illustrate how shipping companies can undertake a customer cooperation programme and achieve sustainability in their operations through CO_2 emission reductions.

However, Borja and Dauer (2008), while noting that many methodologies with hundreds of indices, metrics and evaluation tools are currently available, noted that in order to deal with the complexities of socio-environmental issues, many countries have adopted the DPSIR (Drivers-Pressure-State-Impact-Response) framework (Atkins et al., 2011). DPSIR is an environmental management paradigm as a feedback loop system in which driving forces (D) of social and economic development exert pressure (P) on the environment thereby changing its state (S), potentially resulting in impacts (I) on human health and/or ecosystem function that may elicit an environmental management response (R). Economic development, such as a port expansion, will invariably increase environmental pressures, some of which will be ameliorated through specific management actions.

For example, increasing a port area will cause the loss of estuarine habitats such as mudflats or salt marshes or disturb overwintering wading birds or fishes such as eels and salmon migrating between the sea and the catchment (McLusky and Elliott, 2004). Such relationships between society and in this case logistics and SCM impacts on the environment, and responses to such impacts, can be formalised through the development of the DPSIR systems-based approach (Atkins et al., 2011).

The ten tenets criteria of environmental management

Integrated environmental management requires many aspects to be combined into a holistic system (Elliott 2014). The problems caused by materials (e.g. pollution) or infrastructure added to the system or removed from the system (e.g. aggregates, wetland space) require a risk assessment framework. This is then managed using the actions through vertical integration of governance and the horizontal integration of stakeholder action. Those actions are required to ensure the natural system is protected and maintained while at the same time the benefits required by society are delivered. Such a combined framework and set of tools is then termed the Ecosystem Approach (Elliott 2014).

Consideration of these interactive environmental relationships gives rise to assessing whether the strategy or strategic option fulfils various criteria related to environmental management. Elliott (2013) proposed the 'ten tenets' of environmental management to facilitate such assessment so that management of and a solution for an environmental problem will be sustainable and not environmentally deleterious. Further, they should fall within what is possible in the real world while taking note of the socio-economic and governance aspects. Finally, fulfilling the ten tenets would also mean that environmental management would potentially be seen by wider society as achieving sustainability and in turn would be more likely to be accepted, encouraged and successful. The ten tenets are listed in Table 1 and are self-explanatory although Barnard and Elliott (2015) interrogate and quantify these further for port and marina operations. . We now turn to setting and structuring of environmental problems using a revision of the DPSIR approach: the DAPSI(W)R(M) method (pronounced *dapsiworm*).

Table 1 – The Ten-Tenets of Environmental Management (Source: adapted from Elliott, 2013 and Barnard and Elliott 2015)

Socially desirable/tolerable: Environmental management measures are required or at least are understood and tolerated by society as being required; that society regards the protection as necessary.
Ecologically sustainable: Measures will ensure that the ecosystem features and functioning and the fundamental and final ecosystem services are safeguarded.
Economically viable: A cost-benefit assessment of the environmental management indicates (economic/financial) viability and sustainability.
Technologically feasible: The methods, techniques and equipment for ecosystem and society/infrastructure protection are available.
Legally permissible: There are regional, national or international agreements and/or statutes which will enable and/or force the management measures to be performed.
Administratively achievable: The statutory bodies such as governmental departments, environmental protection and conservation bodies are in place and functioning to enable successful and sustainable management.
Politically expedient: The management approaches and philosophies are consistent with the prevailing political climate and have the support of political leaders.
Ethically defensible: How costs of acting are determined and calculated for current and future generations.
Culturally inclusive: Notwithstanding actions are desired and tolerated by society there may be some cultural considerations taking precedence.
Effectively communicable: Communication is required among all the stakeholders to achieve the vertical and horizontal integration encompassed in the foregoing nine tenets.

The DAPSI(W)R(M) problem structuring method

There were some anomalies in the DPSIR approach that have been rectified in a new, enhanced DAPSI(W)R(M) approach (Wolanski and Elliott, 2015; Burdon et al., in press; Elliott et al., submitted), and which we adopt here for this paper. The Drivers of basic societal needs (D) remain the same however they now requires Activities of society (A) that in turn generate the Pressures resulting from these activities (P). The Pressures are mechanisms that effect a State change on the natural system (S) that in turn generates Impacts on human Welfare (I(W)) that are changes affecting wealth creation and quality of life. These revised Impacts on human Welfare lead to Responses that can be verified as Measures (R(M)).

The ten-tenets relate to actions or management measures that are important for all stakeholders and are available from and carried out by the relevant stakeholders. Within the DAPSI(W)R(M) approach, State changes and Impacts on human Welfare together represent the changes to the receiving environment, direct human interaction with the environment is represented not just by Responses and Measures, but also by the Drivers as the demands on the system leading to the Activities causing the Pressures.

The ten tenets for sustainable management predominantly apply to society and the economy rather than the natural environment; Barnard and Elliott (2015) emphasise that nine out of the ten have a societal and economic basis. Hence the assessment of environmental change is not restricted solely to natural environmental aspects of the Pressures (i.e. the management measures introduced in response to the State changes) but also to the human consequences (i.e. the Impacts on human Welfare). In essence, we assess the Pressures, State changes and Impact (on human Welfare) but we manage the Drivers and Activities. Indeed, 'environmental management' can be regarded as a misnomer in that we are not managing the environment but rather the people and their actions. For example, we assess the change to the seabed during port dredging but we manage the dredging frequency, intensity, extent and duration.

The Bow-Tie analysis

To integrate the DAPSI(W)R(M) approach and the ten-tenets criteria we adopt the Bow-tie risk management analysis as shown conceptually in Figure 2. Fault tree analysis (FTA) and event tree analysis (ETA) have been used for risk assessment for many years. However, these techniques share a common objective, which is to provide an assurance that a process or a system is designed and operated under an 'accepted risk' or a 'threshold' criterion together. Both FTA and ETA can be used together in what is known as a bow-tie analysis (Ferdous et al., 2012; Cormier et al, 2013). FTA provides a graphical relationship between the undesired event and basic causes of such an occurrence while ETA is a graphical model of consequences that considers the unwanted event as an initiating event and constructs a binary tree for probable consequences with nodes representing a set of success or failure states. The follow-up consequences of the initiating event in ETA are usually termed as events or safety barriers, and the events generated in the end states are known as outcome events.

Both techniques use the probability of (e.g. failure or success) basic events and events as quantitative inputs and determine the probability of occurrence for the top-event as well as outcome events for likelihood assessments. The ISO industry standard (IEC/ISO 2009) Bow-tie analysis has been long used in industries especially those constructing and operating new plant such as power stations (Cormier et al., 2013). It is a combined concept that integrates both techniques in a common platform, considering the top-event and initiating event as linked to a common event called a critical event. Like FTA and ETA, Bow-tie analysis also uses the probability of failure of basic events as input events on the FTA site and the probability of occurrence (either failure or success) of events as input events on the ETA site for evaluating the likelihood of critical and outcome events. For quantitative Bow-tie analysis the probabilities of input events are required to be known either as precise data or defined probability density functions (PDFs) if uncertainty needs to be considered. If such quantitative information is not known then an expert judgement approach can be taken although of course this may produce only a semi-qualitative set of outcomes.

As with any risk assessment and risk management approach, the Bow-tie analysis method is initially a qualitative model for displaying links between causes, hazards and consequences, but can be further developed with quantitative modelling. For example, Baysian Belief Network modelling based on probabilities of cause and effect has recently been linked to Bow-tie analysis (Stelzenmüller et al 2014; ICES, 2015). By linking this method to a DAPSI(W)R(M) approach based on ten-tenets criteria, it enables scoping, identification and analysis of:

i) the causes (based on the Drivers, Activities and Pressures) leading to the main events;
ii) anticipatory prevention measures (the Responses using Measures), including those limiting the severity of the main event;
iii) the consequences of the events (the State Changes and the Impacts on human Welfare), and
iv) mitigation and compensation measures (i.e. the Responses using Measures) aimed at minimising those consequences (Burdon et al., 2015).

Figure 2 shows a conceptual Bow-tie analysis model for *inter alia* three potential environmental issue causes related to ocean and short-sea transport and docking at port. As a subset of environmental causes from Figure 1, examples of these causes could be CO_2 and SO_2 emissions into the water (A), ballast water discharges into the water while in port (B), and acidification (C). Consequences of these causes could include *inter alia* high levels of biological pollutants in the receiving environments (water and sediment); (E), harmful air emissions around the ship (F), and an increase in human illness and disease as a result of increased emissions, discharges and acidification (G).

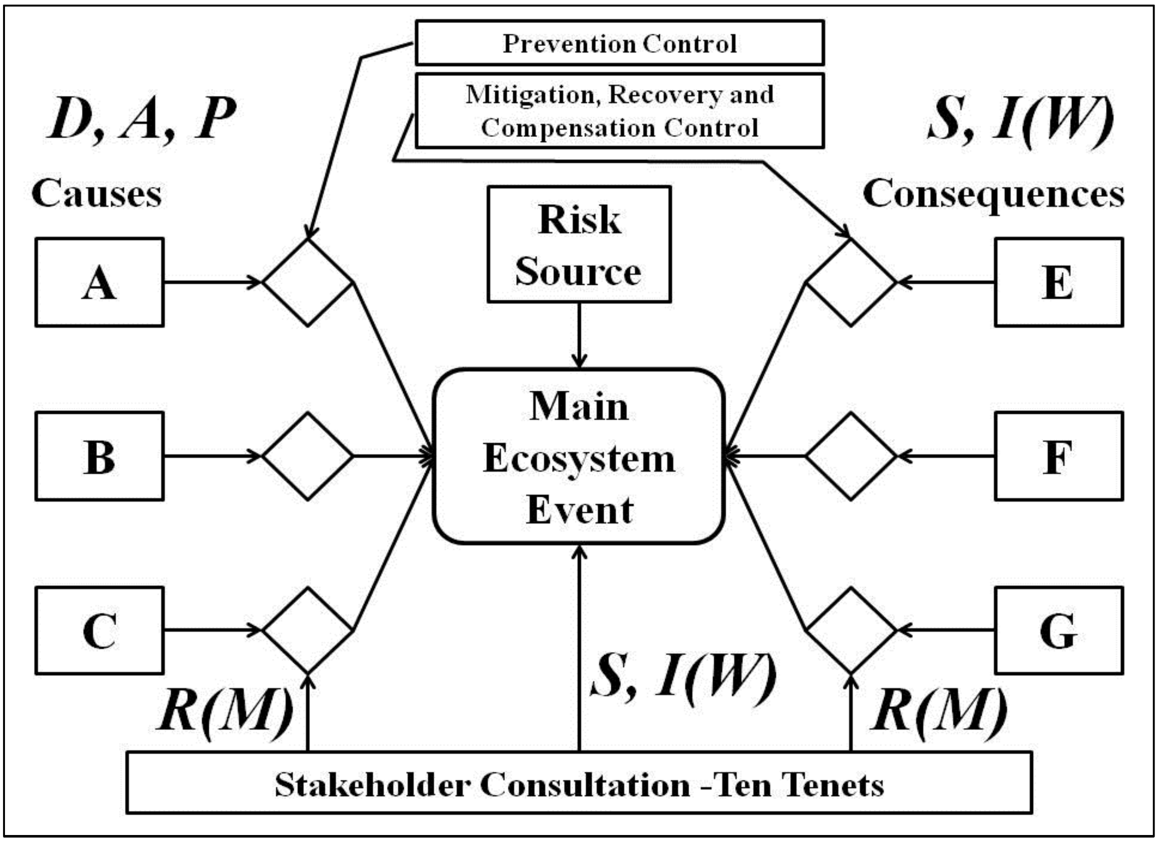

Figure 2 –Proposed Framework

Specific application related to ballast water discharges

For simplicity of explanation we select only one cause, ballast water discharges (B), for further analysis and illustration. A vessel taking on ballast-water in one global region, with its particular fauna and flora, and transporting and discharging it in another region thus leads to the transport of those alien, invasive or non-indigenous species (NIS) which have the potential to disturb the ecological balance at the receiving area (Olenin et al., 2011; David and Gollasch, 2008). As an ancillary vector of NIS, organisms can be transported on the hull, anchor and anchor chains. The various ten-tenets criteria would need to be formalised to provide guidance regarding what Response and Measures could be undertaken for prevention control as well as mitigation, recovery and compensation control. Our example formalisation for them is shown in Table 2 and we have provided subjective comments and an individual ranking for the ten criteria from 1 to 5, representing *not important at all* (score of 1) and *very important* (score of 5).

The completion of these elements in Table 2 provides a view of the State change on the natural system (S) in an ecosystem event that in turn generates Impacts on human Welfare (I(W)) and subsequent consequences. The importance of these then fits with the ultimate aim in marine management being to protect and maintain the natural functioning while delivering the ecosystem services and their resultant benefits required by society (Elliott, 2011). We consider most of these criteria as important to avoid the consequences selected, as well as any others not contemplated in this example. The ratings in the second column of Table 2 reflect our subjective assessment of the criteria that were defined in Table 1.

Table 2 – The Ten Tenets Applied to Ballast Water Discharges

Socially desirable/tolerable	Very important; score =5
Ecologically sustainable	Very important and easy to do; score = 5
Economically viable	Neutral but should not cost too much; score = 3
Technologically feasible	Important and should be easy to do; score = 4
Legally permissible	Important and should not be difficult to follow legislatively; score = 4
Administratively achievable	Important and should not be difficult to administer; score = 4
Politically expedient	Important and a vote winner; score = 4
Ethically defensible	Important and should not be difficult to justify; score = 4
Culturally inclusive	Not an issue; score = 1
Effectively communicable	Important and should not be difficult to communicate; score = 4

We next formulate our main ecosystem event process from a risk source related to water, i.e. a ship at sea or docked at a port development that is summarised in Figure 3. The highlighted boxes outline our specific example of ballast water discharge for consideration, which is especially relevant given that receiving ferry ports in the Baltic Sea region, e.g. Helsinki or Stockholm, show elevated levels of NIS (Olenin et al., 2011). Again, this manifests as an ecological change and the loss of ecosystem service and societal benefits.

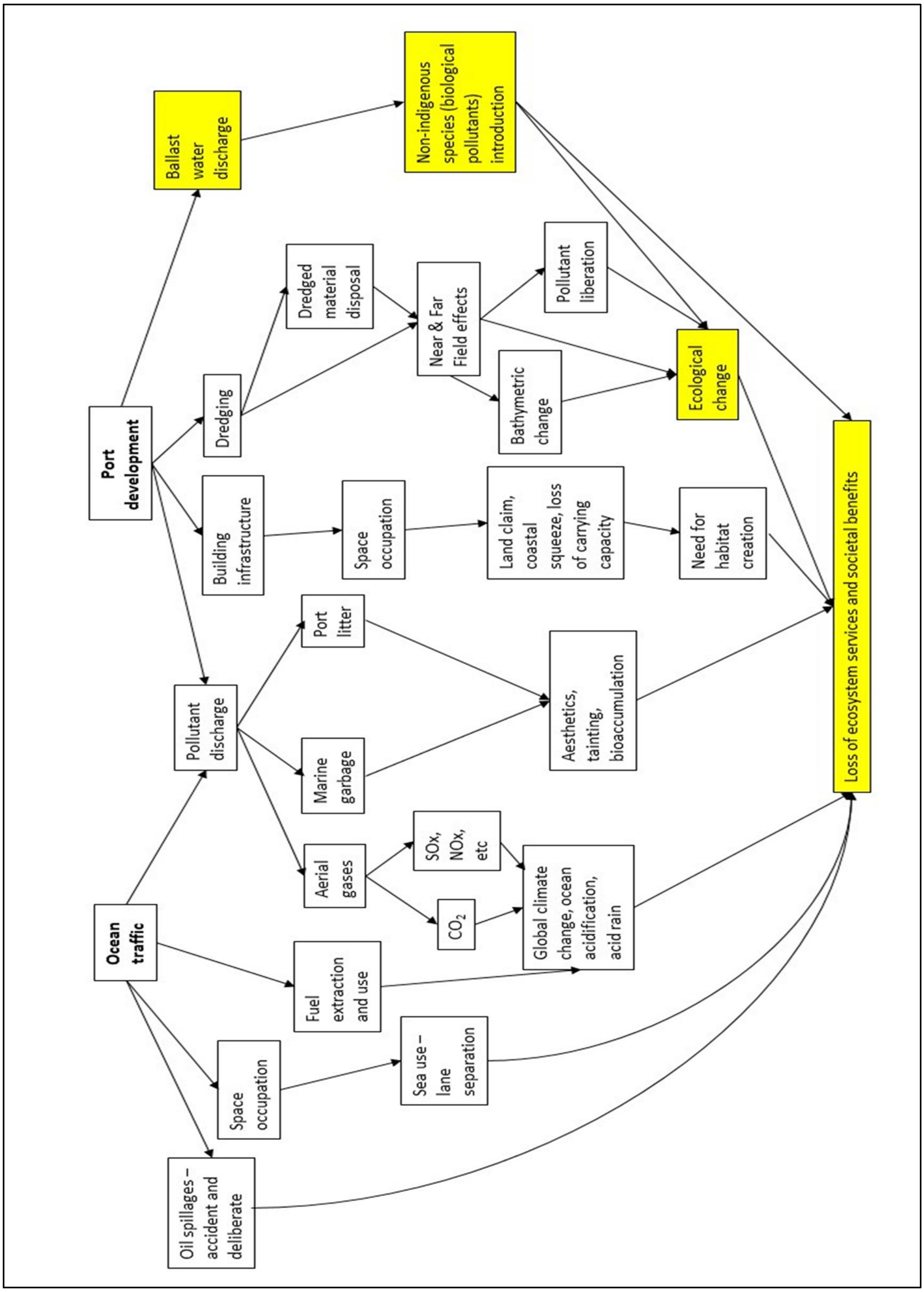

Figure 3 –Example model of ocean traffic and port development environmental effects including Bow-tie Analysis of ballast water discharge main ecosystem event (highlighted boxes)

The Response and Measures for prevention control on the causation side of the Bow-tie could include monitoring of discharges through all of a ship's discharge ports via effluent sensors during each port of call along its route. The monitoring would need legislative support but while monitoring is not a preventative measure *per se*, it is required to determine whether any control mechanism is effective. This will allow the authorities to know whether or not a ship has discharged any dirty ballast water, what the polluting components might be, and their percentage composition in the sample. Continuous monitoring would provide a baseline of what might be considered 'normal' as well as what might be excessive.

If such a prevention control analysis determined that two ships were responsible for the excessive discharges, then distinct mitigation, recovery and compensation controls could be applied as required. For example, mitigation could include preventing the two ships from sailing onward until their ballast water systems were repaired; it is axiomatic that with NIS entry from ballast water discharges it is not possible to eradicate the species in receiving marine waters once liberated (Olenin et al., 2011) and so the emphasis has to be placed on 'prevention rather than cure'. Ballast water exchange en route will partially control the introduction of NIS, as long as there are no 'stepping stones' for organisms to hop across shipping routes, and disinfection of ballast water through, for example, ozone treatment, would prevent NIS discharge either en route or at the receiving port.

We contend that the framework detailed here is merely a formalised and rigorous approach which summarises the risk assessment and risk management carried out daily by port and navigation managers. The strength of this framework comes from the interaction of many causes and many possible consequences for a particular ecosystem event. While limiting our overriding event of water pollution to one cause or event, ballast water discharges, it is necessary to consider the interactions among other potential causes or events occurring simultaneously, for example ballast water discharges, dredging, oil spillages and other pollutant discharges.

Hence, a major challenge in port and navigation management is to include the cumulative and in-combination effects of all activities within the shipping sector, between the shipping sector and other uses and users of the seas, and between those uses and users. Thus within this conceptual framework, the ten-tenets set the scene for what should be normative, proper activities while the DAPSI(W)R(M) approach allows for a systemic and holistic consideration of the causes and consequences using the principles of bow-tie analysis. As shown by Boyes and Elliott (2014, 2015), the control on marine activities and their repercussions requires an extensive legislative and administrative control which ranges from the international (e.g. the International Maritime Organisation), through the regional (e.g. in Europe the EU Directives such as the Marine Strategy Framework Directive and the Maritime Spatial Planning Directive) to national legislation.

Conclusion

This paper has presented an integrative conceptual framework for balancing hard, quantitative environmental sciences and soft, qualitative management sciences. Our simple example illustrates the way that the framework can be used in practice by researchers, businesses, governments and other stakeholders. In doing so it makes a contribution and also brings together work in logistics and SCM and the estuarine sciences. However, this relatively new framework is the culmination of several concurrent but different strands of research primarily in marine sciences. Thus, there is a need to empirically test the framework in an-depth research studies to verify it veracity and robustness. Its success depends on the adequacy of our conceptual knowledge of the causes and consequences of human activities, our understanding of the structure and functioning of the marine system and our ability to quantify those interactions. It requires port and navigation managers to embrace the plethora of decisions affecting the environmental, economic, technical, societal and legal frameworks and hence will need greater training in these aspects. It also requires the environmental managers and regulators to understand the constraints of global port and shipping operations. With greater information and further data it will be possible to convert the framework described here to a decision support system aiming for real-time management of the activities and their consequences.

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THE INFLUENCE OF EXPLORATION AND EXPLOITATION ON SUPPLY CHAIN FLEXIBILITY FIT AND FIRM PERFORMANCE

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Abstract
This paper examines the relationship between ambidexterity—exploitation of current capabilities alongside simultaneous exploration of new competences—and supply chain flexibility (SCF). It also explores the impact of this relationship on supply chain (SC) competence and firm performance. A significant body of research indicates that ambidexterity can improve a firm's or unit's survival rate in uncertain environments, but the mechanisms that produce this effect have not yet been sufficiently analyzed. Previous literature indicates that the knowledge acquired through exploitation and exploration increases the level of adaptation and flexibility within the environment. The goal of this paper is thus to determine whether SC ambidexterity improves SCF. This paper draws on the literature to propose a new measurement of SCF that takes market demands into account, SCF fit. It also analyzes the impact of SCF fit on SC competence and its subsequent effects on firm performance. The hypotheses are tested with data from 302 manufacturing firms using a SEM methodology. Theoretical and practical implications are discussed.
Keywords: Supply Chain Flexibility, Ambidexterity, Fit.

Introduction
Organizational ambidexterity is an ability that firms can use to simultaneously develop exploitation of their current competences and exploration of new opportunities (Cao et al., 2009; Raisch et al., 2009). Although the recent literature shows that this capability impacts both the operating level (Production Department, Patel et al., 2012) and the supply chain (SC) level (Kristal et al., 2010; Huang et al., 2014), there is little empirical evidence of the impact of ambidexterity on the area of operations (Lin et al., 2007; Tamayo Torres et al., 2011).

Ambidexterity is important not only for its positive impact on performance but also for its role in the implementation of this strategy, for it helps facilitate the survival of the organization or unit (March, 1991; O'Reilly and Tushman, 2013). The literature has not directly explored which processes enable ambidexterity to increase the survival rate of units that implement it, but evidence shows that firms can achieve better adaptation and fit with the environment through learning acquired via exploration and exploitation (McNiff, 2000; Lumpkin and Lichtenstein, 2005; Santos-Vijande et al., 2013). Adaptation to the environment requires flexibility, and ambidexterity fosters flexibility, as it permits implementation of operations based on efficacy (exploitation) and innovation (exploration). Thus this study investigates the impact of adopting SC ambidexterity on supply chain flexibility (SCF).Understanding the antecedents and practices that improve SCF is very important, as SCF is a key weapon for achieving competitive advantage, especially in more competitive and uncertain markets (Gunasekaran et al., 2001; Gosain et al., 2005). SCF is not only a capability that can be exploited, it also plays a strategic role in the firm (Gerwin, 1993).

One problem that analysis of SCF poses, as Stevenson and Spring (2007) indicate, is the near absence in the literature of valid, reliable measurement instruments. This study seeks to solve this problem by developing a new measurement instrument for SCF, defined as the gap or difference between the manager's view of the flexibility required by the environment and the SC's real or potential flexibility. This definition conceptualizes perception of what is required by reference to what is considered excellent in the sector's firms (Parasuraman et al., 1993). This study measures SCF through fit because all definitions in the literature reviewed include the notion of coordination and congruence with the environment (Das and Patel, 2002; Gong, 2008), even though the measurement instruments do not consider this factor. The measure developed thus takes the requirements and demands of the environment into account. Further, prior studies use fit to measure operating flexibility, strategic flexibility, structural flexibility, and metaflexibility (Lloréns-Montes et al., 2004; Verdú-Jover et al., 2006; Verdú-Jover et al., 2008).

Second, the effect of SCF on SC competence is a controversial issue in the literature because investing in flexibility incurs costs (He et al., 2012) and risks (Fantazy et al., 2009). This study thus also analyzes empirically the impact of SCF fit on SC competence. Although the prior literature indicates that reproduction of firm strategies and practices perceived as excellent leads to better results (DiMaggio and Powell, 1983), controversy exists because some authors indicate that this adaptation strategy yields worse results (Miemczyck, 2008).

Finally, this investigation analyzes the impact of SC competence on firm performance. Although the literature assumes this impact, there is hardly any empirical evidence to support it (Qrunfleh and Tarafdar, 2014). Thus this study makes three contributions to the SCM literature: first, it develops the conceptual definition of SC ambidexterity and analyzes its effect on the level of SCF; second, it develops a new instrument to measure SCF, SCF fit; third, it studies the impact of SCF fit on SC competence as well as the importance of SC to firm performance.

To analyze the objectives proposed, the rest of the article is structured as follows: First, it explains the theoretical foundations of the conceptual model proposed and the hypotheses that compose it. It then presents the research methodology, the analysis performed, the results obtained, and a discussion of them. Finally, it presents the conclusions drawn from this study as well as its limitations and proposes future lines of research.

Literature review and hypotheses

The supply chain ambidexterity

One of the most recent and widely accepted ideas in management is that a firm's long-term success depends on its ability to exploit its current capabilities while simultaneously exploring new competences (March, 1991; Levinthal and March, 1993). This ability, termed ambidexterity (Duncan, 1976), has become the basis for a new research paradigm in the field (Raisch and Birkinshaw, 2008; Raisch et al., 2009).The literature shows no consensus, however, on the compatibility of exploration and exploitation. Older studies generally affirm that these terms indicate opposed and mutually exclusive practices that compete for scarce resources and require completely different abilities, tasks, and routines (Levinthal and March, 1993). In contrast, more recent studies show not only that these abilities are compatible when performed simultaneously (Boer and Laugen, 2008) but also that they lead to better business results (Katila and Ahuja, 2002).

Ambidextrous organizations can exploit their current competences while simultaneously exploring new opportunities (Cao et al., 2009). Developing this practice can help managers responsible for the SC to maintain their competitive advantage, facilitate achievement of an optimal degree of flexibility, and refine existing routines while absorbing new competences inherent in other departments in the firm and in its environment. Taylor and Helfat (2009, p.719) assert that “without the ambidexterity required to link the new with the old, the end result may be a technological advance that fails to meet market needs”. The demonstrated benefits of organizational ambidexterity for the firm make it crucial to study their effect on the SC. Various researchers have analyzed the effects of ambidexterity on the firm’s business units, projects, managerial levels, and inter-organizational alliances (Birkinshaw and Gupta, 2013), but there is still only slight empirical evidence on its implementation in the area of SC.

The theoretical foundation of SC ambidexterity is found in Kauppila (2007): “Our primary conclusion is that a network is the main facilitator of ambidexterity” (p. 3). The nature of the SC network (Stevenson and Spring, 2009) will thus make it easier to implement ambidexterity. SC ambidexterity is a concept introduced by Kristal et al. (2010) and defined as “a manufacturing firm´s strategic choice (i.e. managerial emphasis) to simultaneously pursue both supply chain exploitation and exploration practices” (p. 415). O’Reilly and Tushman (2013) argue that future studies of ambidexterity should not be limited to the firm as unit of analysis but also should include the firm’s larger ecosystem. Benkler (2006) argues that the locus of innovation will progress from the firm to the community with which it interacts. It is thus crucial to analyze ambidexterity in the SC.

According to studies by Cao et al. (2009) and Birkinshaw and Gupta (2013), the construct of ambidexterity has been operationalized indiscriminately in the literature as both balance (He and Wong, 2004) and the sum or combination of the practices of exploration and exploitation (Gibson and Birkinshaw, 2004). Depending on the point of view adopted, the same organization may thus be classified as having either a high or a low degree of ambidexterity, thereby decreasing the rigor of previous studies. Further, studies use different methods of measuring ambidexterity. Ambidexterity understood as the combination of exploration and exploitation has been measured as both the sum and the product of exploration and exploitation. If, in contrast, ambidexterity is understood as balance or equilibrium, studies measure the absolute value of the difference between exploration and exploitation. A third, mixed method considers ambidexterity simultaneously as the product of the two terms and takes the difference in their absolute values (Birkinshaw and Gupta, 2013). According to the meta-analysis developed by Junni et al. (2013), combined measures of ambidexterity capture its effects better than measures using balance, which suggests that the best effects of this strategy are obtained by combining high levels of exploration and exploitation, not when an optimal point or balance between the two practices is sought. This study thus conceives SC ambidexterity as the combination of both practices.

Supply Chain Flexibility Fit

Flexibility is an object of great interest in the current literature on Operations Management (Gaimon and Singhal, 1992). The study of flexibility focused initially on the capability for flexibility in the organization, subsequently on the study of manufacturing flexibility, and most recently on SCF. This interest has arisen through researchers’ and practitioners’ realization that flexibility is a key weapon for achieving competitive advantage, especially in the most competitive markets and those with the greatest uncertainty (Gunasekaran et al., 2001; Gosain et al., 2005). The importance of SCF stems from the fact that firms do not compete in isolation but within the network that composes their SC (Lo and Power, 2010).

Having a flexible SC can be a reactive capability, but it can also play a strategic role in a firm. In environments with some uncertainty, firms with a flexible SC can derive a competitive advantage from their flexibility (Gerwin, 1993). For Gerwin (1993), this flexibility is not only a response that enables an organization to adapt to uncertainty in the environment, it also functions to create uncertainty that competitors find difficult to contend with.

Despite numerous studies, the literature reviewed presents several limitations that require further research. First, there is no commonly accepted definition of SCF (Gong, 2008), and when SCF is operationalized, it usually includes dimensions belonging to manufacturing flexibility, thus making differentiation between the two difficult. Second, SCF is studied predominantly from the perspective of the firm, without taking the whole SC into account (Candaci et al., 2011).

SCF is a complex, multidimensional concept. Most articles that study it draw their definitions from concepts of firm flexibility and manufacturing flexibility. Further, there are multiple theoretical models of SCF (Duclos et al., 2003; Lummus et al., 2003; Gosain et al., 2005). Despite this diversity, the great majority of theoretical definitions analyzed refer to adaptation to the environment. Das and Abdel-Malek (2003) define SCF as "the robustness of the buyer-supplier relationship under changing supply conditions" (p. 171). For Stevenson and Spring (2007), a flexible SC can adapt effectively to interruptions in supply and changes in demand while maintaining constant levels of delivery of services to the customer. For Gosain et al. (2005) "SCF refers to the extent to which supply chain linkages are able to adapt to changing business conditions rather than being forced into committed adaptation to a given environment" (p.10).

While most studies consider the best SC to be the most flexible (Stevenson and Spring, 2009), some attempt to determine the best degree of flexibility (Graves and Tomlin, 2003; Gong, 2008), thereby creating a controversy. Given that investment in flexibility incurs both costs and risks for a firm, firms must be able to achieve the optimal level of flexibility required in each SC, though the disagreement makes it difficult for them to determine just what that optimal level is (He et al., 2012; Fantazy et al., 2009).

Attempts in the literature to measure SCF are at an early stage (Stevenson and Spring, 2007), so it is necessary to develop and establish measurements that are valid and reliable. To date, research has focused on identifying the theoretical dimensions that define this concept, and there are hardly any sufficiently validated instruments (Moon et al., 2012). Further, although the studies reviewed note that conceptualization of SCF always includes reference to adaptation to the environment. The few measurement scales developed do not consider this adaptation, thereby creating incongruence. This study thus develops a new instrument to measure SCF.

Das and Patel (2002) estimate that measurement of SCF must consider the flexibility needed, thus they link flexibility to the uncertainty experienced by the operations systems in manufacturing firms. Gong (2008) likewise highlights the fact that measuring SCF must take market demands into account. For Gosain et al. (2005), one of the processes that makes the SC flexible is its dynamic fit, the process by which firms can, through learning supported by Information Technology and adaptation capability, effectively and rapidly reconfigure a set of inter-organizational processes appropriate to the changing environment. Based on these contributions, SCF should be determined by its fit. This approach has been used to measure strategic flexibility, operating flexibility, structural flexibility, and meta-flexibility (Lloréns-Montes et al., 2004; Verdú-Jover et al., 2006; Verdú-Jover et al., 2008).

Fit is understood as the internal consistency between a set of fundamental variables related at a theoretical level (Venkatraman, 1989), that is, as the degree to which the needs, demands, objectives, and structure of one component are consistent with the needs, demands, goals, objectives, and structure of another component (Wright and Snell, 1998). The first studies that analyze the relationship between flexibility and fit consider the two concepts as extremes on a continuum and thus opposed to the extent that fit and flexibility cannot coexist in the same entity (Milliman et al., 1991). In contrast, Wright and Snell (1998) find that these concepts are independent and can be complementary. Fit can therefore be considered a temporary state, whereas flexibility is an internal variable of the organization (Lloréns-Montes et al., 2004).

Volberda (1996) distinguishes between two kinds of flexibility: real flexibility, which indicates the current capability of flexibility in the firm; and required flexibility, which refers to the flexibility that managers perceive as demanded by their environment.

This study thus proposes the concept of SCF fit as defined as the gap or difference between the managerial perception of flexibility required by the environment and the real or potential flexibility of the SC. SCF fit is conceptualized as a managerial ability that varies based on changes in the environment and in the manager's perception of it, since perceptions in matters of flexibility have been shown to condition the SC members' actions (Stevenson and Spring, 2009). A SC that achieves the level of dynamic fit required by the environment will produce a zero flexibility gap, either because its capability for flexibility changes as the environment requires or because it is in a situation of temporary equilibrium that does not require new adaptation of the SC. The flexibility gap will be a value other than zero if there is an excessive level of flexibility, with the attendant problems of inefficiency or insufficient level of flexibility, both of which involve the failure to adapt to the changes in the environment (Barrales-Molina, 2008). SCF fit produces a quantitative measurement of the degree to which the SC is as flexible, as it needs to be to succeed in its sector. Put another way, an evaluation is obtained that expresses the SC's degree of adaptation to the environment (Verdú-Jover et al., 2004, 2005).

The impact of Supply Chain Ambidexterity on Supply Chain Flexibility Fit

One of the first studies to analyze the connection between ambidexterity and flexibility is Adler et al. (2009), which proposes that the combination of exploration and exploitation in operating processes leads to long-term improvement in flexibility. Brunner et al. (2008) term this effect "intentional perturbation." O'Reilly and Tushman (2013) conclude that the importance of ambidexterity for an organization lies not only in its positive impact on a series of performance variables but also in its increase of a firm's survival rate in uncertain environments. Santos-Vijande et al. (2012) show that learning facilitates flexibility, which in turn enables implementation of operations based on efficiency (exploitation) and innovation (exploration) through a flow of accumulated experience and new knowledge that inspires creativity and, ultimately, achievement of competitive advantage. Organizations that learn can capture relevant information at any moment in a more precise way, a capability that enables them to anticipate market tendencies and discard routines that are no longer operational.

McNiff (2000) determines that organizations' learning enables them to neutralize threats in the environment, take advantage of market opportunities, and even influence future evolution of the market. Khazanchi et al. (2007) suggest that the capability to adapt to the environment is characteristic of units that promote simultaneous exploration and exploitation. Popadiuk (2012) affirms that the purpose of the learning process (derived from the combination of exploration and exploitation) leads to adaptation to a new context. Through the approach of dynamic fit, Gosain et al. (2005) show that organizations in the SC learn to adjust rapidly, suggesting that learning is the element that causes this fit. Environments characterized as dynamic require greater flexibility than more static ones. Previous research recognizes that learning can strengthen the firm's ability to recognize opportunities and achieve continuous fit with the environment (Lumpkin and Lichtenstein, 2005).

A competitive environment requires simultaneous achievement of efficiency, sensitivity, and speed, which means that organizations must learn from their competitive environment. This learning process is complicated, since firms with slow, inappropriate responses are penalized, which limits the possibility of experimenting and trying new tools in the environment (Hansser-

Bauer and Snow, 1996). To achieve a good response to the environment (which is simply a good SCF fit), firms must explore and exploit simultaneously.

Ambidextrous organizations can exploit existing competences while simultaneously exploring new opportunities (Cao et al., 2009). This form of management can help SC managers to maintain their competitive advantage by achieving the optimal degree of flexibility through redesign of existing routines while simultaneously absorbing new competences from other departments of the firm and from the environment. Taking the foregoing into account, one can expect SC ambidexterity to facilitate the firm's survival, as it has a direct and positive impact on SCF, specifically on SCF fit. According to the literature reviewed, the following hypothesis is proposed:

H1: Supply Chain Ambidexterity has a positive impact on Supply Chain Flexibility Fit.

The impact of Supply Chain Flexibility Fit on Supply Chain Competence

The behavior of firms cannot be explained by appealing only to rational motives or efficiency. It is also influenced by the context in which the behavior occurs (Rogers et al., 2007). In the process of decision-making, firms usually use their perception as a reference point when considering what actions are desirable, correct, or appropriate for a specific organization embedded in a specific system of rules, values, beliefs, and definitions (Suchman, 1995). Managers therefore tend to reproduce the structures, practices, strategies, processes, routines, etc. of organizations they perceive to be "more successful" (Di Maggio and Powell, 1983). The result of this practice is called isomorphism (Deephouse, 1996).

From this perspective, the decision to adopt a specific structure, strategy, or process is determined partly by the results expected but also partly because adopting it is considered a necessary condition for the ability to compete in a specific market. Few recent studies apply these arguments to the area of Operations Management and SCM (Martínez-Costa et al., 2008; Cai et al., 2010; Liu et al., 2010). In the area of SCM, these arguments have focused almost exclusively on explaining the motives that lead to adoption of practices characteristic of green SCM (González et al., 2008). Applying this approach to research in Operations Management has shown that production managers' actions are not only motivated by reasons of economic efficiency (Miemczyk, 2008); they also experience pressure to satisfy demands from the context in which they act (Rogers et al., 2007). The definition of SCF fit is made operational through the comparison the manager makes of his/her SC to what he/she perceives as an excellent SC. This study measures the SC's degree of adaptation to the demands perceived by the managers.

According to the literature, isomorphism will have a positive effect on SC competence. First, adopting desired routines increases competence. It makes learning more efficient because firms learn not only from their own research and experience but also from other firms whose practices they imitate (Tolbert and Zucker, 1983). Furthermore, isomorphism increases public support (DiMaggio and Powell, 1983), access to resources (D'Aunno et al., 1991), and collective learning (Levitt and March, 1988). However, this is a controversial issue. Some evidence shows that isomorphism leads to worse results in terms of economic efficiency (Miemczyck, 2008), as it can cause less differentiation from the competition (Heugens and Lander, 2009) or require significant investment to adopt strategies and configurations similar to those of the most successful firms (Barreto and Baden-Fuller, 2006). Most of the studies reviewed suggest that the strategy of reproducing the most successful organizational practices has a positive impact on business competences, it is reasonable to expect that a SC whose flexibility more closely resembles the flexibility of a SC that is perceived to be excellent shows better competence. Based on this discussion, the following research hypothesis is proposed:

H2: Supply Chain Flexibility Fit has a positive impact on Supply Chain Competence.

The impact of Supply Chain Competence on Firm Performance

Chow et al. (2008) define SC competence as “a portfolio of organizational, managerial, technical and strategic capabilities and skills developed by enterprises over time. Adequate supply chain competence enables enterprises to respond reliably to market demands at any time” (p. 667). Bowersox et al. (2000) define this competence as a supply chain´s ability to respond to customer demands with low cost, high-quality products and services. Green et al. (2014) define “supply chain competence as a reflection of supply chain performance, as opposed to the performance of the individual partnering firms” (p.127). Performance shows how a firm achieves its financial and market objectives. According to the previous literature (Li et al., 2006), and due to the difficulty of obtaining objective data on business performance, business performance is measured as managers’ perception of their market share and rate of sales growth relative to their competition (Narasimhan and Das, 2001).

Fisher (1997) is one of the first studies to highlight the importance of SC competence and its impact on firm performance to show the negative impact the lack of flexibility has on organizational performance. In recent years, the scholarly literature has shown the importance of SCM as a means of improving firm performance (Martínez-Sánchez and Pérez-Pérez, 2005). A positive relationship between SC competence and firm performance is thus expected, since the SC capabilities imply efficacy and efficiency, which assume improvement of the firm’s processes. In spite of the qualitative evidence for this relationship, it has hardly been tested in prior studies (Qrunfleh and Tarafdar, 2014). According to these arguments, the following research hypothesis is proposed:

H3: supply chain competence has a positive impact on firm performance.

Figure 1 illustrates the relationships proposed for empirical validation in the theoretical model developed.

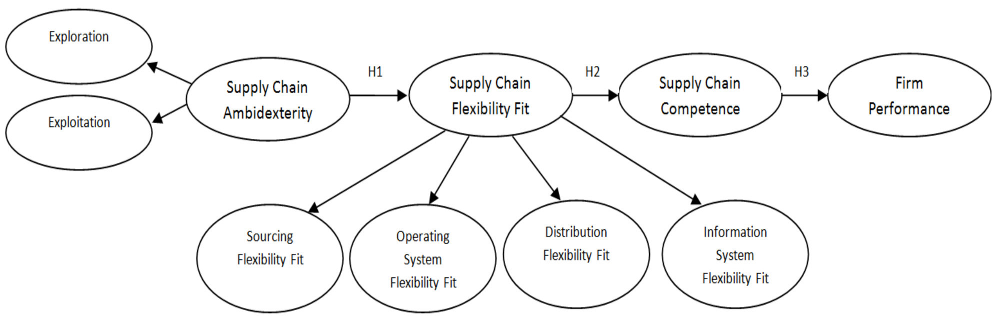

Figure 1 – Theoretical framework of the study

Methodology

Survey design and sample

A detailed survey was designed to gather specific information on the practices of exploration and exploitation, SCF, SC competence, and firm performance as well as demographic data from firms and their respondents. Most of the questions in the survey were answered on a seven-point Likert scale. The questionnaire items were drawn from the literature. The questionnaire was developed by implementing the three-stage procedure followed by Moore and Benbasat (1991) and detailed by Mackenzie et al. (2011).

To provide empirical evidence on the different research hypotheses proposed, the set of manufacturing firms was established as study object. The study population was obtained from the SABI 2014 database (Iberian Balance Sheet Analysis System), which is composed of 45,166 firms. Only firms that belonged to the manufacturing sector and provided complete data in their record (correct phone number, non cessation of activity, and had more than 10 workers) were considered, leaving a total of 2517 firms. The survey was addressed to those responsible for the firm's SC, the purchasing manager or the top manager.

The data was obtained through computer-assisted telephone interviews (CATI) performed in May 2014. 302 complete questionnaires were obtained, getting a response rate of 12%. The sampling error is 5.23%, with a confidence level of 95% (Z= 1.96) for p=q=0.5.

To analyze the presence of possible non response bias in the sample, the study confirmed whether there were significant differences between the firms that responded first and those that answered at the end of the fieldwork. To do this, the sample was divided into responses obtained first (n=170) and responses received after more than one telephone call (n=132). As no significant differences between the firms that responded first and those that responded at the end were found for any of the model variables, the results support the absence of significant non response bias.

Measurement scales

This study uses eight first-order constructs (exploration, exploitation, sourcing flexibility fit, operating system flexibility fit, distribution flexibility fit, information system flexibility fit, SC competence and firm performance) and two second-order constructs (SC ambidexterity and SCF fit).

The scales used to measure the variables were adapted from prior studies to guarantee their validity and reliability. All of the questionnaire items were accompanied by a seven-point Likert scale, where 1 indicates maximum disagreement and 7 maximum agreement with each item.

SC Ambidexterity is measured multidimensionally through exploration and exploitation in the SC, according to the scales proposed by Kristal et al. (2010).

To adapt the scale for SCF fit, the measurement concept used was that developed in the studies by Volberda (1999, 1992), Llorens-Montes et al. (2004), and Verdú-Jover et al. (2006) Flexibility fit was operationalized using the definition of a gap that includes the differences between what the managers perceive their sector to require and what they perceive to happen in their firm. The managers were thus asked about the elements that compose their firm's SCF and requested that they evaluate the requirements of their sector relative to these elements. The flexibility gap was obtained by the difference in the evaluations of the sector relative to the evaluation of the firm.

The items used by Moon et al. (2012) were divided to measure the SCF to ask the survey respondents about real and required flexibility. These authors distinguish four dimensions of SCF: sourcing flexibility, operating system flexibility, distribution flexibility, and information system flexibility

One thus obtains:

- A gap equal to zero (required flexibility–real flexibility=0), which indicates that the SC has flexibility that permits it to change to fulfill the demands of the environment.

- A gap greater than zero (required flexibility – real flexibility> 0), which indicates that the SC has some rigidity relative to the flexibility required by the environment. The greater the difference, the greater the lack of adaptation to new situations that arise in the environment.

- A gap less than zero (required flexibility – real flexibility<0), which indicates that the SC has an excess of flexibility relative to that required by the environment, with the resulting problems of efficiency.

For the statistical analysis, once the gap was obtained for each SC, the point values obtained were transformed to adapt them to a scale from 1 to 7 used to measure the other model constructs. The transformation method used was that employed by Llorens-Montes et al. (2004)First, we converted the differences into negative absolute values so that 0 becomes the highest value on the scale and the increase in distance with regard to 0 indicates a greater misfit in relation to the required flexibility. The more negative a value is, the worse its situation will be with regard to the environmental requisites. Secondly, so as to homogenize the figures to be used in the statistical analysis, we have turned negative values on the scale in positive values between 1 and 7. Thus, the scale values on the flexibility gap in absolute values are similar to those of other constructs for which we have used a Likert-type 1 to 7 valuation. However, in this case, the categories do not correspond to the level of agreement or disagreement with the statement implied in each item, but, rather, refer to the degree of fit (value=7) or level of difference between the required and real values (from 6 down to 1), 1 reflecting the greatest discrepancy

For the SC competence, the scale proposed by Qrunfleh and Tarafdar (2014) was used.

Finally, the firm performance was measured by adapting the scale proposed by Dess and Robinson (1984) to measure organizational performance.

Confirmatory Factor Analysis

The measurement model was evaluated using confirmatory factor analysis (CFA) (Gerbing and Anderson, 1988). Schumacker and Lomax (1996) recommend focusing on modeling in two steps, first evaluating the measurement model to ensure its fit and then examining the full model. The measurement model evaluates discriminant and convergent validity, whereas the full model evaluates predictive validity. Jöreskog and Sörbon (1993) emphasize that the measurement model should be tested independently to ensure that the indicators chosen to measure each construct are appropriate. EQS 6.2 software was used to evaluate the measurement model, as well as the structural model. The estimation method chosen was based on the normality/ non-normality of the data (Bentler, 1995). Since the multivariate normality test showed non-normality of the data (Mardia's coefficient=229.975; t-value=56.562), the robust ML estimation method was applied using EQS software (Bentler, 1995).

CFA was used to evaluate the measurement model, and the reliability and validity of the scales were then tested. The scales' reliability was evaluated using the composite reliability statistics (CR), average variance extracted (AVE), and Alpha Cronbach (Hair et al., 2004). The Alpha Cronbach coefficients were used to measure the internal consistency of the constructs. Given the goal of this study and its use of scales widely employed in the literature, values must be greater than 0.8 for the Alpha Cronbach (Nunnally, 1978; Lance et al., 2006). All statistics calculated for CR took values over 0.7, and the AVE statistics calculated took values over 0.5. These results show acceptable values for reliability and internal consistency of the scales (Hair et al., 2004). A CFA was also developed to demonstrate multidimensionality and goodness of fit of the two second-order constructs used in the model, SC ambidexterity and SCF fit. All results obtained guarantee correct fit of the scales used.

Discriminant validity evaluates the extent to which each construct used in the model is different from the others (Bagozzi et al., 1991). Discriminant validity at the construct level was evaluated using the procedures recommended by Voorhees et al. (2015). First, the criterion developed by Fornell and Larcker (1981), which consists of comparing the square root of the AVE to the correlations between the constructs, was used. The square root of the AVE appears on the main diagonal of Table 1 and is greater than the correlations between the constructs, which shows the presence of discriminant validity between the constructs used in the model. Table 1 show that some of the correlations between the constructs are significant, as expected. Kenny (2012) suggests, however, that discriminant validity between latent factors in SEM is poor if the correlations are higher than 0.85, and no pair of correlations exceeds this limit. Second, the HTMT ratio (Henseler et al., 2015) was calculated for each pair of constructs. The HTMT ratio obtained is lower than 0.85 for each pair of constructs, also indicating the presence of discriminant validity. Finally, following Howell (1987) and Szulanski (1996), discriminant validity was analyzed at the item level.

Table 1 – Correlation matrix

	1	2	3	4	5	6	7	8
1.Expl	0.923							
2.Exlr	0.501**	0.826						
3.SCC	0.305**	0.398**	0.754					
4.FP	0.221**	0.227**	0.376**	0.869				
5.SFF	0.455**	0.447**	0.314**	0.219**	0.847			
6.OSFF	0.411**	0.420**	0.301**	0.201**	0.483**	0.937		
7. DFF	0.408**	0.426**	0.390**	0.282**	0.431**	0.481**	0.904	
8. ISFF	0.445**	0.459**	0.343**	0.278**	0.499**	0.402**	0.444**	0.746

** significant at a significance level of 0.01. The square root of the AVE appears on the main diagonal in bold.

Analysis and discussion of the results

Fit of the structural model

The analytical methodology followed is based on confirmatory modeling. This method consists of specifying a model whose relationships have been established according to theory and using SEM to evaluate its statistical significance.

To evaluate the study hypotheses, the overall fit of the proposed model was analyzed. The global fit indices of the structural model indicate that the theoretical model tested fits the sample data well (Bollen and Long, 1993) (Chi square= 5448.095; p<0.001; IFI=0.949; NNFI=0.942; CFI=0.948; RMSEA=0.05). This suggests that the equations that define the model are a good representation of the information.

Hypotheses testing results

Table 2 shows the estimation values of the standardized coefficients for the representative parameters for each research hypothesis as well as their respective significance levels.

Table 2 – Structural equations model

Parameters and Relationships	Standardized coefficients (t-value)	R^2
Supply Chain Ambidexterity → Supply Chain Flexibility Fit	0.500** (12.227)	0.250
Supply Chain Flexibility Fit→Supply Chain Competence	0.423** (6.860)	0.179
Supply Chain Competence →Firm Performance	0.401*** (6.503)	0.160

The results show a significant and positive impact of SC ambidexterity on SCF fit (β=0.500; t=12.227; p <0.05), thus empirically confirming Hypothesis 1, as proposed in the theoretical framework. This result shows the extent to which ambidexterity is found to be positively related to SCF fit. To date, this relationship has received only slight attention in the literature. This result is consistent with the results obtained by Kristal et al. (2010), Tamayo Torres et al. (2011) and Patel et al. (2012), all of whom show the efficacy of the practice of ambidexterity in the area of Operations Management. The evidence provided underscores the importance of SC ambidexterity as an antecedent of SCF. The knowledge acquired via exploration and exploitation allows rapid adaptation to market evolution and facilitates capturing the relevant information in a more precise way and anticipating market tendencies, thus enabling the SC to have the flexibility required by the environment. This result shows that adopting the practices of exploration and exploitation simultaneously is a good strategy for achieving the level of SCF that the environment requires. Ambidexterity avoids incurring both excess rigidity and excess flexibility in the SC. This result also provides empirical evidence for the exclusively theoretical proposition by Kauppila (2007) that adopting a strategy of ambidexterity is plausible in the organizational areas that compose a network.

The results also show a positive and significant impact of SCF fit on SC competence (β=0.423; t=6.860; $p<0.05$)' and provides empirical evidence to confirm Hypothesis 2 of the proposed model. It can be affirmed that fitting SC strategy to the demands of the environment in matters of flexibility positively influences SC competence. The smaller the SCF gap, the better the results obtained in the SC's efficacy and efficiency. This result is consistent with the propositions that argue that successful systems move toward an ideal state through a dynamic process (Webb and Pettigrew, 1999; Zajac et al., 2000). Furthermore, this result responds to the controversies found in the literature reviewed on whether satisfying the needs managers perceive as related to the environment has a positive impact on competence. The evidence found in this study shows that SCs that the better SCs adjust their flexibility to their context, the higher the level of their competence. They thus show that a strategy to improve SC competence consists of establishing the level of flexibility best adapted to the demands perceived. This result is also consistent with previous studies of Martínez-Costa et al. (2008) and Liu et al. (2010).

Finally, there is a significant and positive relationship between SC competence and firm performance (Hypothesis 3, β= 0.401; t=6.503; $p <0.05$), which is consistent with the studies by Li et al. (2006) and Qrunfleh and Tarafdar (2014). Improving efficacy and efficiency in the SC thus has positive and significant implications for organizational results. If a SC has high competence, the firm will see its results improve, since better competence means lower cost, better quality, and a decrease in delivery time. The result indicates that those firms that improve their SC competence show better business results relative to the competition. In the literature reviewed, this relationship is usually assumed (Martínez-Sánchez and Pérez-Pérez, 2005), although it is not tested empirically. The evidence shows the importance of differentiating between SC level and organizational level as well as the influence of SCM on firm performance. This study thus confirms that SCM can become a key competitive weapon for firms.

Conclusions, limitations and directions for future research

The results demonstrate empirically that there is a positive relationship between the implementation of SC ambidexterity (performing practices of exploration and exploitation simultaneously), SCF fit, SC competence and firm performance.

This study makes important contributions to the prior literature. First, although ambidexterity has been studied in depth in other areas, it has received little application in the literature on Operations Management and, particularly SCM (Patel et al., 2012). This paper provides deep understanding of the theoretical definition of SC ambidexterity and its impact on SCF. This is thus one of the first studies to analyze implementation of exploration and exploitation practices in an organizational network.

Second, this study has developed and analyzed SCF fit as a measurement instrument. The division of the items into different dimensions allows the measurement proposed in this study to take into account the effect of the environment on the fit, a key issue in the theoretical definition of SCF, yet one not quantified in most measurement scales in the SCM literature. This study thus offers a reliable and valid scale that permits comparison between different SC. It is of vital importance to have metrics with good psychometric properties to test and advance theory.

Third, the strategy of adapting the level of flexibility to the demands of the environment shows positive results at SC level. Some evidence in the prior literature supports the thesis that this strategy has a positive impact on performance, while other studies confirm its negative impact on the results. The current study thus attempts to clarify this relationship.

Fourth, this study has overcome one of the common limitations in most empirical studies of SCF that analyze its direct impact on the firm. This study analyzes the effect of SCF on the SC itself. Numerous authors have indicated the benefits for the firm of considering the SC as a single entity (Croom et al., 2000).

For managers, the results highlight the importance of using practices of exploration and exploitation in the SC. Since ambidexterity is a key antecedent for achieving a SC that is as flexible as the environment requires, SC managers must not focus exclusively on practices that pursue efficiency but must also make them compatible with those of innovation if they are seeking to improve SCF. This study thus provides a measurement instrument that permits managers to diagnose the flexibility level of the SC they manage and its lack of correspondence (if this is the case) with the optimal level, as well as to establish comparisons between different SC. Finally, the study demonstrates the importance of SCM on the firm performance, as well as the need to consider the SC as a single entity.

In spite of the important contributions of this study for both the academic and managerial fields, it has several limitations. First, since a single respondent was used to obtain the data, there is a risk of common method bias. To attempt to solve this problem, the study tried to identify respondents who were experts on the questions studied, following the recommendation by Vachon and Klassen (2006), and used a series of procedural and statistical measures to minimize the risk of this bias. Future studies could, however, confirm the results obtained by using various key informants, following the recommendation by Junni et al. (2013) of using multiple informants on ambidexterity.

Second, the research was not able to analyze the impact of ambidexterity on SCF over time. Very few studies analyze ambidexterity with longitudinal data (Raisch et al., 2009), and future studies must incorporate this dynamic component. Likewise, when evaluating SCF fit with cross-sectional data, there is the risk of analyzing a temporary situation in the organization but not its capability for flexibility over time.

Third, SC ambidexterity, SCF fit, and SC competence were evaluated from the perceptions of one manager from one of the firms composing the SC. Following Stevenson and Spring (2007), it is crucial that future studies incorporate the perceptions of other members of the same SC.

Furthermore, it would be interesting for future studies to analyze ambidexterity in the SC on different levels simultaneously, given its nature as a multilevel phenomenon (Raisch and Birkinshaw, 2008; Birkinshaw and Gupta, 2013), as well as to incorporate analysis of knowledge flows in the SC, as analyzed by Mom et al. (2007). This study can also be a useful starting point for development of new measures of SCF fit that adopt the same methodological approach.

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THE MODERATING EFFECT OF IT COMPETENCE ON THE RELATIONSHIP BETWEEN AMBIDEXTERITY AND SUPPLY CHAIN FLEXIBILITY. AN EMPIRICAL ANALYSIS

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Abstract

Supply chain flexibility (SCF) has become an important competitive weapon for companies in the current environment characterized by dynamism. In this context, this paper uses the resource-based view (RBV) and the theory of dynamic capabilities to explore the influence of supply chain (SC) ambidexterity on SCF. It also theorizes the moderating effect of IT competence on the relationship between SC ambidexterity and SCF. Whereas prior research focuses on the positive results of SCF for business performance, little empirical research studies its facilitators, leaving a gap this study seeks to fill. Following the literature on hierarchy of capabilities, this study proposes that SCF is a higher-order capability, and that the presence of lower-order capabilities such as IT competence facilitates the relationship between SC ambidexterity and SCF. These hypotheses are tested with data from a survey of 302 manufacturing firms using hierarchical regression methodology. As expected, the study confirms that SC ambidexterity is an antecedent of SCF and has a positive moderating effect on IT competence. Finally, theoretical and practical implications are discussed.
Keywords: Ambidexterity, Supply Chain Flexibility, IT competence

Introduction

Supply chain flexibility (SCF) has been identified as one of the most relevant topics in research on supply chain management (SCM). Having a flexible supply chain (SC) is a key weapon for achieving competitive advantage in the current environment, characterized by dynamism, uncertainty, and unpredictability (Braunscheidel and Suresh, 2009; Gunasekaran et al., 2001).

For this reason, a significant body of literature has emerged to study SCF. While abundant, this literature focuses specifically on studying the benefits and effects reported, and SCF's positive effect on firm performance is widely recognized (Ngai et al., 2011). A significant gap exists in the literature, however; hardly any studies develop deeper understanding of the strategies and practices that facilitate SCF, a gap indicated by Swafford et al. (2006). Although an abundant prior literature shows that SCF leads to greater performance, no agreement exists on the different ways of achieving this improvement.

Taking this background into account, the current study provides a theoretical framework of strategies and capabilities that improve SCF. Specifically, it focuses on practices related to knowledge management, analyzing the impact of SC ambidexterity, as well as the positive moderating effect of IT competence on this relationship.

The study thus first asserts that implementation of SC ambidexterity can have a positive effect on SCF, conceptualizing SC ambidexterity as the simultaneous implementation of practices of exploitation of current knowledge and exploration and creation of new knowledge (Kristal et al., 2010; March, 1991). Although the benefits of ambidexterity at organizational level have been widely researched (O'Reilly and Tushman, 2013), they have received very little study in the area of SC operations (Im and Rai, 2008; Patel et al., 2012). Evidence exists that better adaptation to the environment is achieved by means of the learning acquired via exploration and exploitation(Lumpkin and Lichtenstein, 2005; McNiff, 2000; Santos-Vijande et al., 2012), and adaptation to the environment requires flexibility (Krajewski et al., 2005). The strategy of ambidexterity thus has a positive effect on SCF. Further, basing its arguments on the resource-based view (RBV) and the theory of dynamic capabilities, this study proposes that SCF is a dynamic, or higher-order, capability facilitated by simultaneous implementation of knowledge exploration and exploitation practices in the SC.

Second, the positive moderating effect of IT competence on the relationship between SC ambidexterity and SCF is analyzed. Few studies explore the effects of IT competence on the SC (Gosain et al., 2005; Swafford et al., 2008; Vickery et al., 2010).Empirical study of the mechanisms underlying IT capabilities in this context is needed (Ray et al., 2005; Wu et al., 2006), since it is common business practice to use numerous IT in SCM (Fawcett et al., 2011). From the RBV, Wade & Hulland (2004, pp.109) hold that “information systems exert their influence on the firm through complementary relationships with other firm assets and capabilities.”. It is thus argued that the effect of IT competence on organization occurs through other organizational capabilities and assets, since IT competence is a lower-order capability whose presence facilitates other higher-order capabilities (Liu et al., 2013). Since SCF is a dynamic capability, it is proposed that the influence of ambidexterity on SCF will be strengthened in the presence of high IT competence, as the latter facilitates greater coordination in management of the knowledge obtained through exploration and exploitation, due to increased speed in perceiving change and adapting SC connections (Gosain et al., 2005). This relationship is thus grounded in prior studies, such as that by Perez Lopez et al (2009), which demonstrates empirically the facilitating effect of IT competence on knowledge management practices, encouraging development of organizational structures that facilitate the development and expansion of knowledge, a result also supported in the study of Chuang et al. (2013). Analyzing ambidexterity and IT competence together is crucial yet unexplored, as Sher and Lee (2004, pp. 934) argue, “IT is an indispensable element in current knowledge management practices”

This article thus seeks to make three contributions to the literature of IT and SCM. The first is to deepen understanding of the conceptual definition of SC ambidexterity and to study its effects on the level of SCF. The second is to study the moderating effect of IT competence on this relationship. The third is to use the RBV and its extension in dynamic capabilities to explain the relationships between SC ambidexterity, SCF and IT competence.

To analyze these goals, the rest of the article is structured as follows: Section 2 presents the theoretical foundations of the conceptual model proposed and the hypotheses that compose it. Sections 3 and 4 present the research methodology and analyses performed, as well as the results and discussion of them. Finally, Section 5 confirms the study’s conclusions and its limitations and future lines of research.

Theoretical framework and hypotheses development

Supply Chain Ambidexterity

The concept of ambidexterity has seen growing interest in organizational theory, becoming one of the paradigms for current research (Raisch et al., 2009). Ambidexterity is understood as the ability to exploit current knowledge while simultaneously exploring and creating new knowledge (Levinthal and March, 1993; March, 1991).

The first studies of ambidexterity focused on determining whether exploration and exploitation practices could be compatible. Whereas older studies hold that the tasks or routines required for exploiting existing knowledge differ completely from those used for exploring new, and even warn of the risks of falling into “failure traps” and “success traps” (Levinthal and March, 1993), subsequent studies show the compatibility of the two (Cao et al., 2009), considering exploration and exploitation as two parts of the same learning process. Since this compatibility has been demonstrated, current research focuses on analyzing its benefits. The benefits of implementing ambidexterity have been demonstrated on the level of the organization, business unit, project, and alliance between companies(O’Reilly and Tushman, 2013), but there has been very little study in the area of operations and the SC (Im and Rai, 2008; Tamayo-Torres et al., 2011). In this context, our study develops deeper understanding of SC ambidexterity.

The current study adopts the conceptualization by (Kristal et al., 2010, pp. 415) of SC ambidexterity as “a manufacturing firm’s strategic choice (managerial emphasis) to simultaneously pursue both supply chain exploration and exploitation practices.” This strategy is justified by the fact that it is easier to implement ambidexterity in organizational networks (Kristal et al., 2010), since this involves combining the organization’s own knowledge with external knowledge and since the SC is “the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer”(Christopher, 2005 pp. 17). Along these lines, O’Reilly and Tushman (2013) argue that research on ambidexterity should not limit its scope to the area of the firm but should extend to the firm’s strategy with the agents with which it interacts.

The literature reviews on ambidexterity by Cao et al. (2009) and Birkinshaw and Gupta (2013) indicate incongruences in the prior research. To advance study of this topic and obtain consistent results, research must resolve the problems detected, which are described as follows. The main problem in the research to date is operationalization of the construct of ambidexterity indiscriminately as both balance (He and Wong, 2004) and the sum or combination of the practices of exploration and exploitation (Gibson and Birkinshaw, 2004). Depending on the point of view adopted, the same organization may thus be classified as having either a high or a low degree of ambidexterity. Further, the way of measuring ambidexterity differs from study to study. Ambidexterity understood as the combination of exploration and exploitation has been measured as both the sum and the product of the constructs of exploration and exploitation. In contrast, studies that understand ambidexterity as an equilibrium between the two practices measure the absolute value of the difference between exploration and exploitation. A third, intermediate method considers ambidexterity as having two dimensions: the balance between exploration and exploitation and their combination (Birkinshaw and Gupta, 2013). According to Junni et al. (2013), considering ambidexterity as a combination of these two practices captures its effects better than measures that consider it as a balance between exploration and exploitation. The best effects of this strategy are thus obtained when high levels of exploration and exploitation are achieved simultaneously, not when an optimal point or balance between the two practices is sought. This study thus conceives SC ambidexterity as the combination of both practices.

The resource based-view (RBV) and dynamic capabilities

In the research on Strategic Management, the theoretical framework currently most used to explain the success of firms is the resource-based view (RBV). The RBV explains the foundation of strategies that enable achievement of competitive advantage (Ray et al., 2005). This focus argues that only from assets, resources, and capabilities that unite valuable, rare, imperfectly imitable, and non-substitutable (VRIN) characteristics can firms develop strategies to achieve competitive advantage and greater benefit than their competition (Barney, 1991).

The theory of dynamic capabilities develops from the static perspective of the RBV, beginning with the study by Teece et al. (1997). According to this theory, in unpredictable environments with high uncertainty, a firm may at a given moment possess the resources indicated by Barney (1991), but this does not guarantee a competitive advantage sustained over time (Helfat and Peteraf, 2003).Dynamic capabilities enable the firm to achieve a long-term competitive advantage. Teece et al. (1997, pp.516) define them as "the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments." According to Zollo and Winter (2002), dynamic capabilities are a complex set of abilities through which organizations systematically modify their operating routines and reconfigure their resources and abilities to achieve good adaptation to the changing demands of the market.

Some authors have attempted to establish how these capabilities are related amongst themselves, establishing a hierarchy among them (Rai et al., 2006; Sambamurthy et al., 2003). They thus usually differentiate between fundamental, or lower-level, and higher-level capabilities. Higher-order capabilities, developed through lower-order ones, lead the firm to obtain better benefits and to achieve competitive advantage. Lower-order capabilities in themselves have no impact on entrepreneurial benefits but influence them through their role of facilitating higher-order capabilities (Grewal and Slotegraaf, 2007; Kraaijenbrink et al., 2010).

Supply Chain Flexibility

The current business environment, characterized by uncertain demand and a high degree of volatility, presents a challenge for SCM, as it requires firms to possess flexible supply chains. Flexible SCs are able to adapt effectively to interruptions in supply and changes in demand, while maintaining constant levels of delivery of service to the customer (Stevenson and Spring, 2007). Tachizawa and Gimenez (2009) define SCF as the ability of the firm's purchasing function to respond effectively, rapidly, and at the lowest cost possible in order to change the requirements for components that it buys in terms of volume, mix, and delivery date. This definition synthesizes the advantaged linked to SCF: efficacy, lower cost, and rapid response. Despite the variety of conceptualizations of SCF, all theoretical definitions describe it as an ability of SC function to react to changes in the environment.

Although multiple theoretical models outline the dimensions of SCF (Duclos et al., 2003; Lummus et al., 2005; Martínez Sánchez and Pérez Pérez, 2005), most share two problems: they confuse two dimensions inherent in manufacturing flexibility with those of SCF, making it harder to establish a clean distinction between the two concepts. They also lack a measurement scale that operationalizes their conceptualization (Stevenson and Spring, 2007). This study thus follows the model proposed by Moon et al. (2012) who solve these two problems. These authors propose that SCF is a construct composed of the following dimensions: sourcing flexibility, defined as the availability of materials and services and the ability to purchase them according to changing needs; operating system flexibility, defined as the capability to provide products with a wide variety of characteristics, combinations, and volumes to satisfy multiple specifications for customers; distribution flexibility, defined as the firm's ability to manage its distributors, warehouses, loading capability, and other distribution installations effectively and efficiently; and information system flexibility, understood as the ability of the firm's information systems to adapt to changing market circumstances, especially in situations of unexpected misfit.

Having a flexible SC can be a reactive capability, but it can also perform a strategic role in the firm. In environments with uncertainty, firms that have a flexible SC can develop a competitive advantage from it (Gerwin, 1993). Following this argument, Gerwin (1993) underscores that SCF not only permits adaptation to change in the environment but also enables the creation of uncertainties that competitors cannot fight. The literature is in nearly unanimous agreement on the positive effect of SCF on organizational performance (Aprile et al., 2005;

Blome et al., 2013; Martínez Sánchez and Pérez Pérez, 2005; Swink et al., 2005). The mechanisms underlying this capability have hardly been researched, however. Since it has been shown that SCF precedes firm benefits and is a source of competitive advantage, research must focus on providing a theoretical explanation, consistent with the prior literature on why SCF has this beneficial effect on business results. Research must also study what strategies and mechanisms encourage achieving these results. This article seeks to fill this gap.

Starting from the demonstrated positive effect of SCF on performance, and following Barney (1997), this study argues that SCF is VRIN, which explains why the prior literature shows it to be a precursor of competitive advantage. SCF is not a question of rules and procedures, a quality that makes it difficult to imitate. Rather, it is a capability generated by coordination and integration among different members and functions of the SC. It is also complex and rare, as it requires management of the SC as a single entity (Croom et al., 2000), and many organizations lack these abilities. Finally, SCF is valuable since, for example, it has the capability to prevent the firm from being affected by interruptions in supply (Blome et al, 2014). This article argues that SCF is not only a VRIN capability, but that it can be considered as a dynamic capability in so far as it can serve the firm to take advantage of opportunities and neutralize threats, and require the firm to modify its operating routines and reconfigure its resources and abilities to adapt to market changes. This argument follows the lines of studies like Blome et al. (2013) and Liu et al. (2013). Its approach of understanding SCF as a dynamic capability is consistent with Makadok (2001), which argues that dynamic capabilities are constructed by the firm and cannot be bought on the market, since SCF requires a way of understanding network connections and the relationships that compose it are thus impossible to acquire.

Effect of Supply Chain Ambidexterity on Supply Chain Flexibility

While ambidexterity has recently begun to be studied in the area of operations and SCM (Kristal et al., 2010; Patel et al., 2012), the relationship of SC ambidexterity to the SC and SCF has not been tackled directly. The first study to propose this relationship tangentially is Adler et al. (2009), which suggests that combining exploration and exploitation in the firm's operating processes improves long-term flexibility.

SCF permits the organization to respond immediately to unexpected market changes. It is important for an organization to be able to learn continually in order to be prepared for any challenge from its environment (Ngai et al., 2011). Organizations that learn from their current competences and current activities (exploitation), while simultaneously integrating this knowledge with knowledge from outside the organization and putting new abilities into practice (exploration), can learn from their customers, competitors, and market situation. Such learning makes it easier for the firm to recognize unforeseen changes and market trends and to react to them (Tippins and Sohi, 2003). Hernández-Espallardo et al. (2010) also show the importance of learning and sharing knowledge in SCs.

Organizational units that learn can capture relevant information precisely and at the right moment to anticipate market tendencies and discard routines that are no longer operational. Khazanchi et al. (2007) stress that capability to adapt to the environment is characteristic of units that promote exploration and exploitation together. Popadiuk (2012) indicates that the learning process (derived from combining exploration and exploitation) leads to adaptation to a new context.

Gosain et al. (2005) show empirically that the organizations that compose the SC learn to adjust rapidly, such that learning facilitates adaptation to the environment and the other SC members. Likewise, Beer et al. (2005) and Lumpkin and Lichtenstein (2005) recognize the role that learning plays in strengthening the firm's ability to recognize opportunities and to adapt continually to the environment. Sharing this study's approach on understanding SCF as a dynamic capability, Ancona et al. (2001) suggest that dynamic capabilities develop from innovations based on exploration and exploitation.

According to the literature review, this study proposes that implementing learning practices based both on refinement and perfection of existing routines and competences (exploitation practices) and on the testing and elimination of new routines and competences (exploration practices) produces recombination of internal and external knowledge that leads to improvement in SCF. We thus formulate the first study hypothesis:

H1: SC ambidexterity has a positive and direct impact on SCF.

Moderating effect of IT competence on the relationship between Supply Chain Ambidexterity and Supply Chain Flexibility

Ray et al. (2005) and Wu et al. (2006) indicate the need to study IT competence in the area of the SC. They define IT competence as the extent to which a firm knows IT and uses it effectively to manage information in the firm (Tippins and Sohi, 2003). As conceptualized by these authors, IT competence is composed of three dimensions: IT knowledge, the extent to which a firm possess a body of technical knowledge of IT objects; IT operations, the extent to which a firm uses IT to manage the market and information on consumers; and IT objects, the hardware, software, and personnel support available to the firm.

Debate exists in the prior literature on the effect of IT competence on business results and achievement of competitive advantage. Whereas some studies, generally the earliest, argue its positive effect on performance (Ray et al., 2005), the most recent (which follow the RBV and hierarchy of firm capabilities, hold that IT competence is a fundamental, lower-order capability that deploys its effects in the firm only through higher-order capabilities, such as SCF (Liu et al., 2013; Rai et al., 2006; Sambamurthy et al., 2003). Wade and Hulland (2004, p. 109) argue that "information systems exert their influence on the firm through complementary relationships with other firm assets and capabilities". Along similar lines, Mithas et al. (2011) argue that IT capabilities facilitate higher-order capabilities.

On the other hand, the facilitating or moderating role of IT in the relationship between other variables has been demonstrated empirically, for example, in the relationship between endogenous knowledge management and improvement of dynamic capabilities, and the relationship between management of exogenous knowledge and improvement of dynamic capabilities (Sher and Lee, 2004).

Taking this background into account, this study proposes that the positive effect of SC ambidexterity on SCF is strengthened when the firm possesses IT competence. Thus, IT competence can strengthen the ability of the knowledge acquired via exploration and exploitation to enable identification of market change more rapidly and to communicate this change to other members of the SC to enable coordination of a joint response. According to the empirical study by DeGroote and Marx (2013) IT competence improves the quality of the information transmitted throughout the SC and coordination of the actions that SC members adopt in response to market changes.

The quality of information communicated through the SC is based on coordinated decision making and actions Simatupang and Sridharan (2008). IT competence can thus play an important role in coordinated decision making, as it permits management of large quantities of data on market changes that should be distributed, assimilated, and used in the SC to achieve flexibility (DeGroote and Marx, 2013).

IT competence has been shown to improve the opportunity, accessibility, precision, appropriateness, and processing of information by means of the SC (Vickery et al., 2010). This capability can also improve the ability of firms in the SC to develop and implement coordinated responses to market changes at the right moment with precision and cost-effectiveness (Yusuf et al., 2004).

From the perspective of knowledge management rather than technology, prior research shows the facilitating role of IT competence in knowledge management processes (Wang et al., 2007), while McDermott (1999) affirms that IT is a crucial dimension to study in knowledge management. Chuang et al. (2013) conclude that IT support is essential in initiating and performing knowledge management activities, as IT permits reuse of current knowledge and rapid tackling of new knowledge needs. Likewise, Perez Lopez et al. (2009) demonstrate empirically the relationship between IT competence and all knowledge management processes (generation, transfer, coding, and storage). Alavi and Leidner (2001) hold that IT-based systems are developed to support and improve organizational processes for the creation, storage, recovery, transfer, and application of knowledge.

We thus propose that the effect of SC ambidexterity on SCF increases when the firm possesses IT competence, since a firm with this capability will be faster in transforming the knowledge obtained via exploration and exploitation to adapt SC configuration to market changes. Without the support of IT competence, information will flow more slowly than is necessary to make the best response to market change (Ngai et al., 2011). Likewise, when supported by IT competence, the learning obtained via exploration and exploitation can lead to lower inventory levels, more rapid design of products, shorter purchase-order cycles, and greater quality in the decision-making process (Cachon and Fisher, 2000; Fawcett et al., 2011; Fiala, 2005), thereby improving SCF. Specifically, we propose the following hypothesis:

H2: IT competence positively moderates the relationship between SC ambidexterity and SCF.

Figure 1 represents visually the relationships proposed for empirical validation in the theoretical model developed.

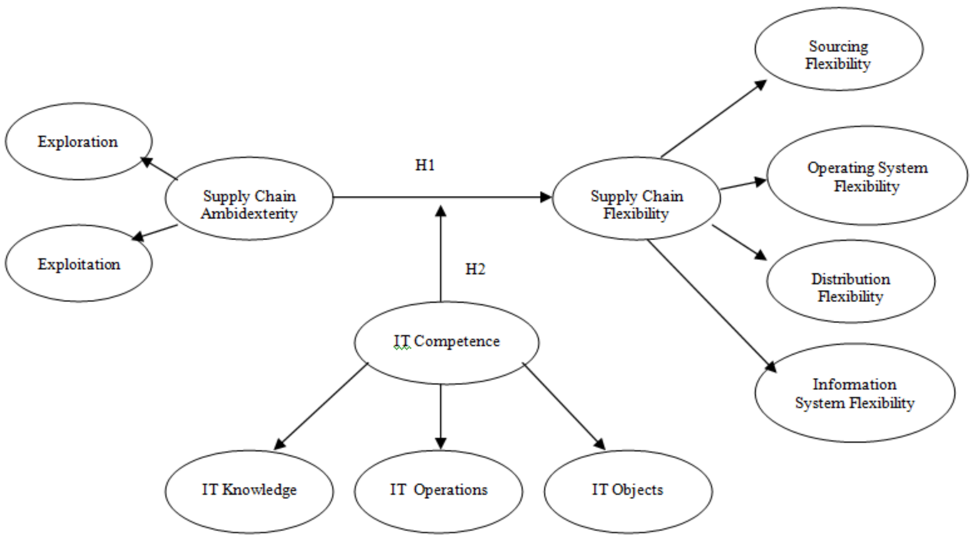


Figure1- Theoretical model

Methodology

Data collection and sampling

A detailed survey was designed to gather specific information about exploration and exploitation practices, SCF, and IT competence, as well as demographic data on the firms and their informants. Most of the survey questions were answered using a seven-point Likert scale. The questionnaire was developed by implementing the three-stage procedure followed by Moore and Benbasat (1991) to ensure the content validity of the measurement instruments employed.

To provide empirical evidence on the different research hypotheses proposed, we established the object of study as the set of Spanish manufacturing firms. The study population was obtained from the 2014 SABI database (Iberian Balance Sheet Analysis System), composed of 45,166 firms. We included only firms in the manufacturing sector that provided complete registry data (correct phone number, had not ceased activity, and had over 10 employees) and obtained a total of 2517 firms. The surveys were addressed to the individuals in charge of the firm's SC or, if this position did not exist, to those in charge of purchasing or to the manager.

To analyze the possibility of non response bias in the sample, we confirmed whether there were significant differences between the firms that responded first and those that responded at the end of the fieldwork. To do so, we divided the sample into responses obtained first (n= 170) and those obtained after more than one phone call (n= 132). We did not find significant differences between firms that responded first vs. last for any of the model variables. The results obtained thus support the absence of significant non response bias.

Measurement scales

The variables of SC ambidexterity and IT competence were operationalized using scales from prior studies to guarantee their validity and reliability. All questionnaire items were answered through the informant's perceptual evaluation using a 7-point Likert scale on which 1 indicated maximum disagreement and 7 maximum agreement.

SC ambidexterity was measured using exploration and exploitation of the SC following the 8-item scale proposed by Kristal et al. (2010). SCF was measured using the 13-item scale developed by Moon et al. (2012).These authors distinguish four dimensions of SCF: sourcing flexibility, operating system flexibility, distribution flexibility, and information system flexibility.Finally, IT competence was measured by adapting the 15-item scale proposed by Tippins and Sohi (2003). The three dimensions these authors propose refer to resources that cumulatively indicate the organization's ability to use and understand IT tools and processes necessary to managing information on the market and demand: IT knowledge, IT operations, and IT objects.

Confirmatory Factor Analysis

The scales were evaluated using confirmatory factor analysis (CFA) with EQS 6.0 software. The scales' reliability was evaluated using the statistics for composite reliability, average variance extracted (AVE), and the Alpha Cronbach (Fornell and Larcker, 1981; Hair et al., 2004). Alpha Cronbach coefficients are used to measure the internal consistency of the constructs (Nunnally, 1978). All statistics calculated for composite reliability and the Alpha Cronbachs take values above 0.7; the AVE values are over 0.5. These values are acceptable, demonstrating the scales' reliability and internal consistency (Hair et al., 2004).

Discriminant validity at the construct level was evaluated using the procedures recommended by Voorhees et al. (2015). First, the criterion developed by Fornell and Larcker

(1981), which consists of comparing the square root of the AVE to the correlations between the constructs, was used. The square root of the AVE appears on the main diagonal of Table 1 and is greater than the correlations between the constructs, which shows the presence of discriminant validity between the constructs used in the model. Table 1 shows that some of the correlations between the constructs are significant, as expected. Kenny (2012) suggests, however, that discriminant validity between latent factors in SEM is poor if the correlations are higher than 0.85, and no pair of correlations exceeds this limit. Second, the HTMT ratio (Henseler et al., 2015) was calculated for each pair of constructs. As Table 2 shows, the HTMT ratio is lower than 0.85 for each pair of constructs, also indicating the presence of discriminant validity. Finally, following Howell (1987) and Szulanski (1996), discriminant validity was analyzed at the item level. The correlations observed in the CFA were compared to the correlation values calculated for the case of perfect correlation. The correlation values calculated must be greater than the values observed. As the results show that this condition is met for all cases; discriminant validity is ensured.

Table 1- Correlation matrix

	1	2	3	4	5	6	7	8	9.
1.ExIr	0.826								
2.ExIp	0.590**	0.923							
3.SF	0.405**	0.365**	0.847						
4.OSF	0.421**	0.427**	0.373**	0.937					
5.DF	0.455**	0.347**	0.402**	0.448**	0.904				
6.ISF	0.511**	0.410**	0.430**	0.408**	0.350**	0.746			
7.ITK	0.173**	0.296**	0.300	0.338**	0.371**	0.306	0.754		
8.ITOp	0.210**	0.231**	0.487**	0.451**	0.411**	0.385**	0.436**	0.754	
9.ITOb	0.196**	0.204**	0.425**	0.414**	0.403**	0.322*	0.340**	0.430**	0.869

** Significance level of 0.01. The square root of the AVE appears on the main diagonal in bold.

Table 2- HTMT ratio

HTMT	ExIr	ExIp	SF	OSF	DF	ISF	ITK	ITOp	ITOb
ExIr									
ExIp	0.837								
SF	0.639	0.499							
OSF	0.593	0.521	0.506						

DF	0.682	0.451	0.581	0.577					
ISF	0.655	0.455	0.531	0.449	0.411				
ITK	0.298	0.441	0.497	0.500	0.584	0.412			
ITOp	0.338	0.322	0.754	0.623	0.605	0.484	0.736		
ITOb	0.380	0.342	0.793	0.689	0.715	0.488	0.691	0.817	

Common method variance

Further guarantee of appropriateness of the measures used was examined through rigorous testing for common method bias, using both procedural and statistical methods (Podsakoff et al., 2003). Although the informants knew they were answering questions related to SCM, learning mechanisms, and IT, it is quite unlikely that they could have intuited the specific research model. If the informants do not know the research question, they are less able to manipulate their responses to attempt to satisfy expectations concerning relationships they presume. We used several response formats (not at all–a lot, maximum disagreement – maximum agreement) and did not group the questions by construct. We also protected the informants' anonymity and pre-tested the survey to eliminate ambiguity, using simple language that was easy to understand. To evaluate the extent of the effect of common method bias (in addition to all of the procedural measures employed to avoid it), we used Harman's one-factor test (Podsakoff and Organ, 1986), performing an exploratory factor analysis of all construct items to eliminate the possibility of obtaining a single factor that explains the majority of the variance. If most of the variance were explained by the first factor, there would be significant bias. In this analysis, only 20.776 % of the variance was explained by the first factor, and the rest of the variance explained was distributed evenly across the other factors (15.276%, 11.037%, 5.659%, 4.951%, 4.283%, 3.297%, 2.891%, 2.691%). We can thus conclude that the potential of common method bias is low.

Hypothesis testing

To verify the different model hypotheses, we performed hierarchical regression analysis with SPSS v.20 software, a methodology used to test moderating effect (Gu et al., 2014; Tamayo-Torres et al., 2010). In the first step, a regression analysis was calculated with SCF as dependent variable and SC ambidexterity as independent variable. The moderating variable, IT competence, was then introduced in the model. Finally, the term representing the interaction effect between SC ambidexterity and IT competence was added. This multiplicative term included in the equation creates problems of multicollinearity, since it correlates with the independent variables that compose it. According to the recommendation by Jaccard et al. (1990), the variables that compose the multiplicative term are taken into account relative to their mean to avoid the problem of multicollinearity. Further, to ensure that the results are not affected by multicollinearity, the variance inflation factors (VIF) were calculated for all regressions. In all cases, they obtained levels well below the recommended maximum, indicating that the results are not affected by multicollinearity. The results of the hierarchical regression analysis are presented in Table 3.

Table 3- Effect of SC ambidexterity on Supply Chain Flexibility

	SCF		
	Model 1	Model 2	Model 3
SC Ambidexterity	0.315*** (5.752)	0.214*** (3.656)	0.229*** (4.015)
IT Competence		0.243*** (4.145)	0.125 (1.986)
IT Competence *			0.252***

SC Ambidexterity			(4.353)
R2	0.100	0.148	0.200
Adjusted R2	0.096	0.143	0.191
F	33.089***	26.029***	24.712***
Change in R2		0.048	0.052
VIF SC Ambidexterity IT Competence IT Competence * SC Ambidexterity	1.000	1.207 1.207	1.212 1.480 1.249

To complete verification of the moderation hypotheses, once a significant moderating effect was found, the strength and nature of the interaction term had to be confirmed, as indicated by Jaccard et al. (1990). An additional regression analysis was thus performed to evaluate the effect of the independent variable on the dependent variable, distinguishing different levels of the moderating variable. Following the recommendation by Jaccard et al. (1990), the observations have a high point-value in the moderating variable when they take values higher than its mean, while the low level of this variable includes the cases that take values below the mean. The results of this analysis are shown in Table 4.

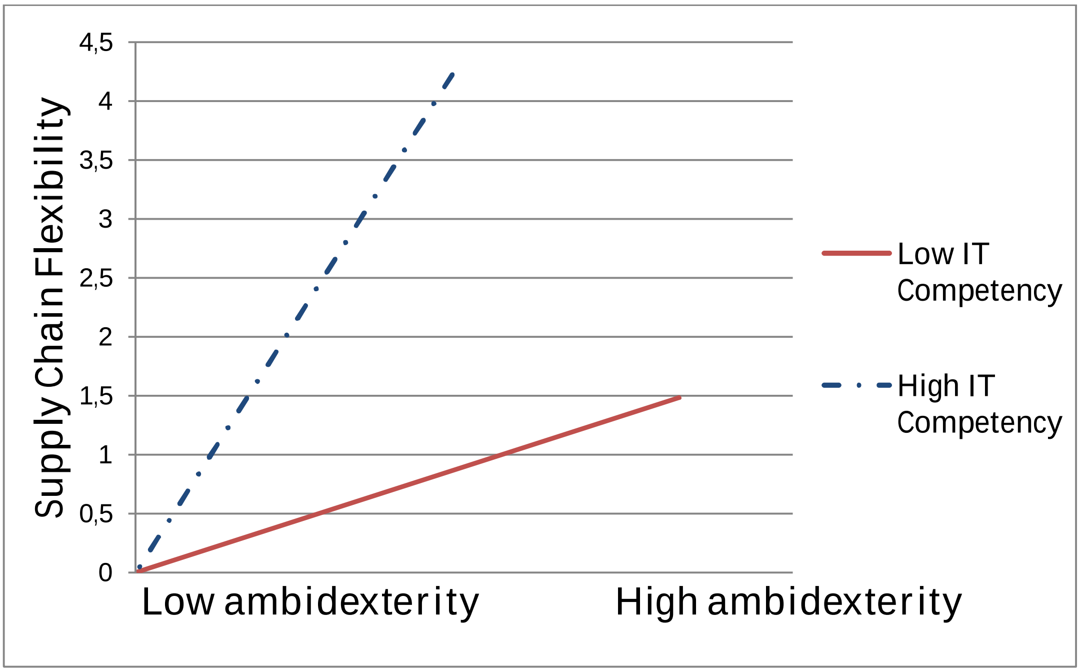
Table 4- Effect of SC ambidexterity on Supply Chain Flexibility for different levels of IT competence

	Model 1 (n=162)	Model 2 (n= 140)
	High IT Competence	Low IT Competence
SC Ambidexterity	0.354*** (4.795)	0.076 (0.892)
R2	0.126	0.006
Adjusted R2	0.120	0.001
F	22.995	0.796

The results obtained confirm Hypothesis 1 of the model (β= 0.315; t=5.752; p <0.01), providing empirical support for the thesis that SC ambidexterity improves SC capability to recognize market changes and enable the firm to react to them.

Second, the results obtained support H2 of the model proposed, as IT competence moderates the relationship between SC ambidexterity and SCF. The results indicate that the positive relationship between these two variables is moderated by IT competence when it is high (β= 0.354; t=4.795; p <0.01). Figure 2 represents the moderating effect of IT competence.

Figure 2- Moderating effect of IT competence



Discussion and implications

Discussion of the results

This study seeks to understand the factors that facilitate SCF. Specifically, it focuses on strategies and capabilities related to knowledge management, the practice of SC ambidexterity, and IT competence. Several relevant implications that help to fill the gaps found in the prior literature can be derived from this study.

First, the results show that SC ambidexterity has a direct and positive effect on SCF. This result answers the firs research hypothesis of the theoretical model proposed. The positive relationship between ambidexterity and SCF indicates that implementing practices for exploitation of existing knowledge and capabilities simultaneously with practices of exploration and creation of new competences and capabilities improves the SC's ability to detect changes in the environment and speed in reacting to them. This conclusion is especially important because the prior literature usually relates only exploration practices to achievement of flexibility (Miller et al, 2006), while this study provides important empirical demonstration that combining these practices with others that tend to refinement and efficiency of current competences increases SCF. This is one of the few studies to relate both exploration and exploitation to improvement of flexibility, indicating that the SC's capability for adaptation and reaction to changes in the environment requires not only innovative practices and experimentation with new ideas and knowledge (exploration practices), but also their combination with practices based on existing strategies and knowledge (exploitation practices). That is, it is not enough to develop new knowledge and innovative capabilities. The firm must also improve existing strategies and competences. This result is consistent with the latest findings in the literature on operations, which show that ambidexterity has beneficial effects in this area (Kristal et al., 2010; Patel et al., 2012; Tamayo-Torres et al., 2011). It is also consistent with the literature that relates different learning mechanisms to adaptation to the environment (Lumpkin and Lichtenstein, 2005; Santos-Vijande et al., 2012).

Second, the moderating effect of IT competence on the relationship between SC ambidexterity and SCF indicates that firms with high IT competence strengthen the positive effect of ambidexterity on SCF. This finding confirms our second research hypothesis, which presents the relationship between IT competence and SCF, as well as the moderating role of IT competence. Given the current market's greater competition for the efficient use of resources, finding complementary relationships and interaction effects between different capabilities is of vital importance. Investment in and improvement of IT competence has been a business constant in recent years, and this result improves understanding of how this capability is connected to others in the SC. We thus show that possessing a high level of knowledge of current technology combined with effective use of this technology improves the effectiveness of SC ambidexterity, as it increases collection, distribution, and use of the information obtained via exploration and exploitation throughout the SC.

The RBV and its extension in dynamic capabilities enable us to explain that IT competence is a lower-order capability that impacts the firm by means of other, higher-order capabilities such as SCF. This result is consistent with the prior literature on hierarchy of capabilities (Kraaijenbrink et al., 2010; Rai et al., 2006).

Finally, this study follows the recommendation by Ray et al. (2005) and Wu et al. (2006) that research must analyze IT competence in the SC.

Theoretical implications

This research makes important contributions to the existing literature. First, it extends the field of study of SC ambidexterity to the SC. Whereas the positive effects of ambidexterity have been reported at the level of the firm, project, or manager (O'Reilly and Tushman, 2013), study of these effects in the SC has been very limited (Kristal et al., 2010). This article continues the line of research in Adler et al. (2009), Im and Rai (2008) and Patel et al.(2011), by incorporating this question into operations research. In so doing, it follows the recommendations by Birkinshaw and Gupta (2013) to make the results obtained more precise and rigorous in conceptualizing flexibility.

Second, the RBV and the theory of dynamic capabilities and hierarchy of capabilities have been applied to explain the relationship between the model variables. This study follows the recommendation of Ketchen and Guinipero (2004) to test models belonging to Operations Management using approaches drawn from strategic management. The theoretical framework developed follows the line of recent studies, such as Allred et al. (2011) and Hollos et al. (2012), which have begun to incorporate the RBV and dynamic capabilities approaches from Strategic Management research in Operations Management. Further, researchers have recently begun to apply the RBV and the theory of dynamic capabilities to interorganizational networks (Smart et al., 2007). This article contributes to this line of research in applying these theories to the SC. From the theoretical point of view, this approach represents a change of paradigm, since it blurs the distinction between what constitutes the firm and what composes its network.

Third, the research shows that SC ambidexterity and IT competence are antecedents and facilitators, respectively, of SCF. The study thus responds to the call by Swafford et al. (2006) for research that develops a deeper understanding of the antecedents of SCF.

Practical implications

This study also makes important contributions to business practice. First, understanding how to foster SCF is crucial, as firms develop their activity in markets that require them to have increasing flexibility, making it crucial for managers to know what strategies and competence development permit improved flexibility. This study shows that performing knowledge exploration and exploitation processes simultaneously facilitates SCF, an effect increased when the firm has high IT competence.

Second, firms have in recent years invested millions of dollars in the attempt to obtain greater profit (Liu et al., 2013). Numerous investments in IT have not, however, translated into increased profit level because managers fail to take into account that IT alone does not have a direct effect on the firm results, but rather affects them through other, higher-order capabilities. This study thus provides a guide to enable managers to make their investment in IT profitable, since it shows what part of IT's business value consists of its positive impact on SCF.

Finally, studying strategies applied to the SC, as well as the use of the RBV in this area, helps managers to recognize that the firm they manage is only a node in a network and that they can create competitive advantage not only based on firm assets but increasingly from the assets and capabilities of the network in which they operate (Cheng, 2011;Smart et al., 2007).Firms must thus concern themselves with managing not only their capabilities but also those of the SC to which they belong.

Limitations and future lines of research

This study has certain limitations. First, it focuses on manufacturing firms that develop their activity in Spain, which can limit generalization from the results to different contexts.

Second, it uses a single informant to obtain the data, with the attendant risk of common method bias. Although a series of procedural and statistical measures were performed to prevent the risk of incurring this bias, future research could confirm the results obtained with various key informants, a procedure recommended by Junni et al. (2013) to improve studies of ambidexterity. Stevenson and Spring (2007) also recommend that future studies incorporate the perceptions of other members of the SC to enable more precise evaluation of its flexibility.

Third, the data used are transversal in nature, so that, in analyzing SCF, there is a risk of analyzing a momentary situation in the organization but not its long-term capability for flexibility.

Finally, future studies could incorporate control variables used in the prior research to measure SCF, since these may impact SCF. Examples could include environmental uncertainty (Kristal et al., 2010), technological level of the firm (Martínez Sánchez & Pérez Pérez, 2005), and production method (Patel et al.,2011).

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MODELLING AND OPTIMIZATION OF SUSTAINABLE BIOMASS BASED ENERGY SUPPLY CHAINS WITH MULTIPLE TECHNOLOGIES

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Abstract

Biomass based energy production have been considered as an emerging area to offer an alternative to the traditional energy systems with limited fossil fuel resources. Organic wastes from different sectors can be treated as biomass feedstock in biomass based energy supply chains. The aim of this research is to present an integrated optimization model to identify the optimum structure of the supply chain and transportation related decisions to meet the energy and biofuel demand of a given region. Economic and environmental objectives, which are represented by the total supply chain profit and greenhouse gas (GHG) emissions, are considered in a multi objective structure. Fuzzy goal programming (FGP), which is one of the most powerful multiobjective decision making approaches, providing the advantage of allowing for the vague aspiration levels, is used as solution approach. To explore the viability of the proposed model, computational experiments are performed on a case study of West Midlands Region in the UK. The optimum structure of the supply chain and optimum values of the objectives are determined considering the priorities of the decision maker (DM) on the objectives.

Keywords: Sustainable supply chains, bioenergy, optimization

1. Introduction

The increased levels of Green House Gas (GHG) emissions and the overall climate change and energy crisis agenda forces many governments across the world to put policies and legislations into action to respond to these growing concerns. The report published by UK Department of Energy & Climate Change (DECC) (2014) shows that energy supply remains the largest emitting sector of UK 2014 GHG emissions with a value of 31% of total emissions. The legislative regulations such as the Kyoto Protocol (1197), the European Union Emission Trading System (2009) and the European Climate Change Programme (2000), force companies to change the way they make their decisions and manage their supply chains in an energy efficient way (Marufuzzaman et al., 2014).

In bioenergy production, a possible solution to energy security issues, similar concerns have been expressed about the environmental sustainability of the sector. Various bioenergy chains are operated throughout the world, consisting of different biomass feedstock production systems, pre-treatment and conversion operations, as well as transportation methods for raw materials and bio-based fuels. However, the wide use of biomass based energy systems has resulted in new challenges. For example, in many cases for the supply of biomass from production areas to energy producing regions, long-distance international transport may be necessary which may result in additional logistics costs, energy consumption and ultimately higher GHG emissions compared to local utilisation. The International Energy Agency states that almost 25% of the energy related CO_2 emissions worldwide result from transportation activities (The International Energy Agency, 2009).

These challenges have motivated researchers to develop proper methodologies to select the most favorable supply chain configuration options and to identify cost-efficient bioenergy supply chain designs with a small carbon footprint. Only effectively designed bioenergy supply chains can have an economic advantage over fossil fuel sourced energy systems and eliminate the issues related to sustainability. Modeling and optimization approaches for biomass based energy supply chain design of increasing scope and sophistication have been proposed in recent years. Among the studies that integrate economic and environmental sustainability in designing bioenergy supply chains, Popp et al. (2011a), Popp et al. (2011b) and Popp et al. (2012) developed a modelling framework consisting of three models, namely the global vegetation and hydrology model, the global land use optimization model MAgPIE, and the global energy–economy–climate model. The framework is capable of representing economically the land and energy sector, investigating the potential contribution of bioenergy to climate change mitigation, including its costs and trade-offs with food and water security in an integrated framework.

Mathematical optimization is widely used by researchers considering its capability to represent the system characteristics successfully. Čuček, L., et al. (2010) and Lam et al. (2013) used MILP modelling to optimise bioenergy networks efficiently on a regional scale. The objective of the model is profit maximisation and the environmental impact is evaluated by the carbon footprint. Giarola et al. (2011) presented a multi-period, multi-echelon MILP framework to optimize the environmental and financial performances of corn grain and stover based bioethanol supply chains simultaneously which is extended in Giarola et al. (2012) by considering a wide set of alternative production technologies and specific geographical features. A further extension of Giarola et al. (2011) with uncertainty consideration can be found in Giarola et al.(2012). They addressed the long-term strategic design and planning of feasible and sustainable multi-echelon bioethanol supply chains by a multiperiod MILP framework aiming at the maximisation of the financial performance and complying with environmental sustainability criteria incorporating a carbon trading scheme. You and Wang (2011) and Santibanez-Aguilar et al. (2011) addressed the optimal design and planning of biorefinery supply chains under economic and environmental criteria represented by total annualized cost/profit and life cycle GHG emissions by determining optimal feedstock, processing technology and product combinations.

Review of the literature suggests that, the vast majority of the studies are limited to only one type of conversion technology, bio-product (biofuel or energy) and biomass resource. However, in real world applications more than one product may be generated from multiple sources of biomass in bioenergy plants, i.e. produced biofuel is commonly converted into energy by power engines. This study contributes to the literature by considering various conversion technologies as well as different types of bioenergy and biomass sources in an optimization model. Also, most of the models in the literature include either biomass to energy conversion or pretreatment activities. Hardly any of the methodologies in the literature integrates the strategic decisions related to location, capacity and technology selection with tactical decisions on production and transportation of biomass and bioenergy for both bioenergy plants and preprocessing facilities. Another contribution of our study is that the proposed model captures collection, pretreatment and conversion phases in an integrated way.

In this paper, a multi objective Mixed Integer Linear Programming (MILP) model is developed to optimize bioenergy supply chains considering diverse biomass to energy conversion technologies, different types of bioenergy and biomass. The model integrates location, capacity, production and transportation related activities to optimize economic and environmental objectives. More specifically, the model maximizes the total supply chain profit and minimizes of the transportation and production related GHG emissions, hence captures the tradeoffs between the revenues and GHG emissions in the supply chain. As biomass to energy conversion technologies, Anaerobic Digestion (AD) and Gasification (G) are considered to meet the biogas, electricity and heat demand in various demand nodes using waste biomass. Decisions regarding collection and pretreatment facilities are also supported by the model. The applicability of the model is illustrated/explored/ or something a bit softer than the word "prove" with a case study of West Midlands Region in the UK and further analyses are performed to quantify the impact of changing parameters as well as the tradeoffs between the profit and GHG emission objectives.

2. Methodology

As the decision problems on renewable energy systems have multiple, usually conflicting objectives, it is important to handle the problem with an appropriate approach. Goal programming (GP) is one of the most powerful multiobjective decision making approaches in practical decision making. However applications of GP to real life problems may be faced with some important difficulties raised from precisely defined goals and constraints. In fact, to ask a DM what attainments are desired for each objective function is a difficult job. In such situations, FGP is an appropriate approach which provides the advantage of allowing for the vague aspirations of the DM. These vague aspiration levels can then be quantified. Formulation of the typical FGP problem can be stated as follows:

$$\begin{aligned}
&Find\ x_i, && i = 1...n \\
&Z_m(x_i) \prec \bar{Z}_m && m = 1...M \\
&Z_k(x_i) \succ \bar{Z}_k && k = M+1...K \\
&g_j(x_i) \leq b_j && j = 1...J \\
&x_i \geq 0 && i = 1...n
\end{aligned} \tag{1}$$

Where, $Z_m(x_i)$ is the mth goal constraint, $Z_k(x_i)$ is the kth goal constraint , $\bar{Z}_m$ is the target value of the mth goal, $\bar{Z}_k$ is the target value of the kth goal, $g_j(x_i)$ is the jth inequality constraint and b_j is the available resource of inequality constraint j.

To formulate fuzzy numbers, membership functions are used. The grade of a membership function indicates a subjective degree of satisfaction within given tolerances. A membership function (μ), assigns to each object of a domain its grade of membership in fuzzy set A. The nearer the value of membership function to unity, the higher the grade of membership of element or object in a fuzzy set A.

To establish the membership functions of objective functions in FGP, upper (u_m) and lower (l_m) limits have to be determined besides the aspiration levels for each goal by the DM. Results, which are obtained by solving the single objective linear programming models considering each time one objective function, can be used as starting points to specify the upper and lower limits. Therefore, the feasibility of each fuzzy goal is guaranteed. The pay-off table includes the maximum and minimum values of these results of each objective that is taken as the aspired level of achievement and the lowest acceptable level of achievement. DM can estimate of the upper and lower values for each goal using payoff table (see Table 1).

Table 1. The payoff table

	Z_1	Z_2	...	Z_M

X^1	Z_{11}	Z_{12}	...	Z_{1M}
X^2	Z_{21}	Z_{22}	...	Z_{2M}
$\vdots$	...	...	...	...
X^M	Z_{M1}	Z_{M2}	...	Z_{MM}

In Table 1, Z_m $(m = 1,\ldots,M)$ denotes the mth objective function, and X^m is the optimal solution of the mth single objective problem. Solving the problem with X^m for each objective, a payoff matrix with entries $Z_{pm} = Z_m(X^p)$ $(m, p = 1,\ldots,M)$ can be formulated as presented in Table 1. Each of the Z_{pm} ($Z_{11}, Z_{12}, \ldots, Z_{MM}$) is called "efficient extreme solutions". Upper and lower limits can be determined, respectively, as follows:

$$u_m = (Z_m)^{max} = \max_p(Z_{pm}) \quad p = 1,2,...,M \tag{2}$$

$$l_m = (Z_m)^{min} = \min_p(Z_{pm}) \quad p = 1,2,...,M \tag{3}$$

$$(Z_m)^{min} \le Z_m \le (Z_m)^{max} \tag{4}$$

After constructing upper and lower limits, the membership functions can be developed for each fuzzy goal and constraint. The membership function for each goal is defined as follows where l_m denotes the lower bound for the mth objective and u_m denotes the upper bound for the mth objective:

For "approximately less than or equal to";

$$\mu_{Z_m}(x) = \begin{cases} 1 & ; \quad Z_m(x) \le l_m \\ \dfrac{u_m - Z_m(x)}{u_m - l_m} & ; \quad l_m < Z_m(x) \le u_m \\ 0 & ; \quad Z_m(x) > u_m \end{cases} \tag{5}$$

For "approximately greater than or equal to";

$$\mu_{Z_k}(x) = \begin{cases} 1 & ; \quad Z_k(x) > u_m \\ \dfrac{Z_k(x) - l_k}{u_k - l_k} & ; \quad l_k < Z_k(x) \le u_k \\ 0 & ; \quad Z_k(x) < l_k \end{cases} \tag{6}$$

In this study a FGP model is developed using "fuzzy and" operator (Werners, 1988), which is one of the most powerful compensatory operators that can be used in setting the objective function in fuzzy programming to investigate better results, to reflect the relative importance of the objectives and provide the DM for a more confident solution set for policy decision making. Using this approach the following LP problem can be formed;

$$
\begin{aligned}
&\textit{Maximize} && \lambda + (1-\gamma)\sum_k w_k \lambda_k \\
&\textit{Subject to} && \mu_{Z_k}(x) \geq \lambda + \lambda_k, \quad k = 1....K, \\
& && \sum_k w_k = 1 \\
& && x \geq 0 \\
& && \lambda, \gamma \in [0,1]
\end{aligned}
\tag{7}
$$

Where K is the total number of objectives, w_k is the corresponding weight for each objective that reflects the importance of the objective according to the DM, $\mu_k(x)$ is the membership function of goal k, and γ is the coefficient of compensation defined within the interval [0,1].

The solution procedure used in this study can be summarized in the following steps;

Step 1: Develop the conventional (crisp) linear programming formulation of the problem (see Section 3).
Step 2: Obtain efficient extreme solutions, i.e. the payoff table (see Table 1) to be used for constructing the membership functions of the objectives. To do this, solve the multi objective linear programming problem as a single objective problem, considering each time only one objective and ignore the others. Determine the corresponding value for each objective function at each solution.
Step 3: Find upper and lower bounds (i.e. u_m and l_m) for each objective from the objective function values derived in step 2.
Step 4: Identify the membership functions using upper and lower bounds.
Step 5: Considering the membership functions, transform the fuzzy model to a linear programming problem by introducing the auxiliary variable λ using "*fuzzy and*" operator.
Step 6: Using the linear programming formulations, find the optimal solution corresponding to fuzzy solution approach.

3. The Model

This section presents multi objective MILP model to design anaerobic digestion and gasification based bioenergy supply chains. The aim is to make decisions corresponding to; (1) procurement and allocation of the resources; (2) configuration of the supply chain network with related connections and capacities; and (3) inventory, production and logistics management, while meeting the energy demand of a particular area. The model determines the optimal configuration of the supply chain considering the tradeoffs between revenue and GHG emissions. To be more precise, to increase the profit we have to transport more feedstock and produce more bioenergy which means at the same time increasing the transportation and production related GHG emissions. Hence, it is important to capture the tradeoffs between conflicting objectives.

Waste biomass (animal wastes and waste wood) is considered to be converted into energy in plants. After animal wastes are collected in collection centers and waste wood is dried and transformed into woodchip in the pretreatment facilities, biomass is transported to the bioenergy plants. The supply chain considered is illustrated in Figure 1.

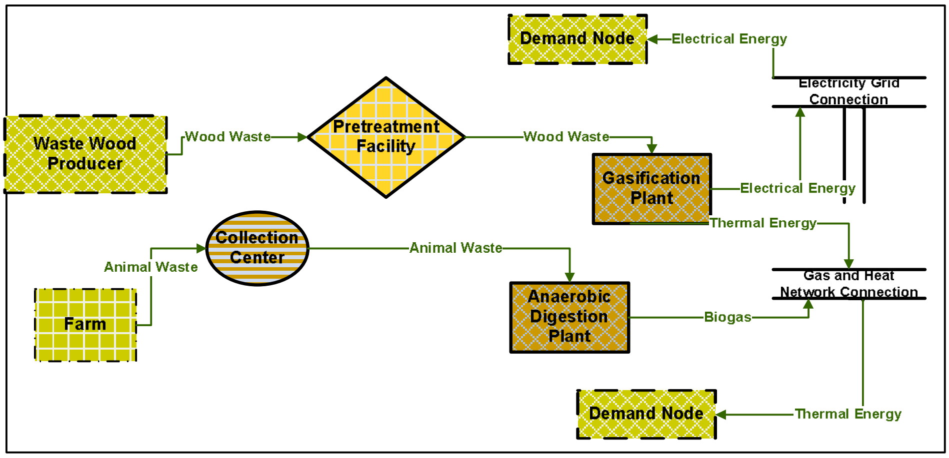

Fig. 1. *An overview of the supply chain under consideration*

The decisions made by the model are;

- Locations and capacities of collection centers, pretreatment facilities, AD and G plants,
- The number of CHP units constructed in the plants as well as corresponding capacities,
- The transportation options used to transport biomass between locations, biomass distribution between supply region to facility as well as from facility to plant,
- The biogas, electricity and heat production amounts in the plants,
- The amount of carbon emissions related to transportation and production activities

Notations and related descriptions for model indices, input parameters and decision variables are presented in Appendix 1.

2.1. The objective function

As stated before, a multiobjective model is proposed to reflect the multidimensional nature of the problem under concern. The model includes environmental and economic objectives. The objectives are: (1) maximization of total profit; and (2) minimization of GHG emissions (CO_2 eq) related to transportation and production in the supply chain. The following equations represent the first objective function.

Total Profit = Total Revenue- (Discounted Investment Costs + Operational Costs + Total Transportation Cost + Biomass Purchasing Cost)

$$
\begin{aligned}
Max\ z = & \left[\left(\sum_{k=1}^{K} \sum_{l=1}^{L} DB^{kl} \cdot PB \right) + \left(\sum_{k=1}^{K} \sum_{l=1}^{L} SE^{kl} \cdot PE \right) + \left(\sum_{k=1}^{K} \sum_{l=1}^{L} SH^{kl} \cdot PH \right) \right] \\
& - \left[\left[\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{m=1}^{M} \sum_{b=1}^{B} TCB_{bm} \cdot d1^{ij} \cdot \left(SC_{mb}^{ij} + SP_{mb}^{ij} \right) \right] + \left[\sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{b=1}^{B} TCB_{bm} \cdot d2^{jk} \cdot \left(SA_{mb}^{jk} + SG_{mb}^{jk} \right) \right] \right] \\
& - \left[DF \cdot \left[\begin{array}{l} \left(\sum_{j=1}^{J} ICC \cdot CapCO^{j} \right) + \left(\sum_{j=1}^{J} \sum_{f=1}^{F} ICP \cdot PT_{f}^{j} \cdot CP_{f} \right) + \left(\sum_{k=1}^{K} \sum_{p=1}^{P} ICA \cdot AD_{p}^{k} \cdot CA_{p} \right) \\ + \left(\sum_{k=1}^{K} \sum_{r=1}^{R} ICG \cdot G_{r}^{k} \cdot CG_{r} \right) \\ + \left(\sum_{k=1}^{K} \sum_{q=1}^{Q} ICHPA \cdot CHPA_{q}^{k} \cdot CCHPA_{q} \right) + \left(\sum_{k=1}^{K} \sum_{v=1}^{V} ICHPG \cdot CHPG_{v}^{k} \cdot CCHPG_{v} \right) \end{array} \right] \right] \\
& - \left[\left[\begin{array}{l} \left(\sum_{j=1}^{J} \sum_{e=1}^{E} OCC \cdot CO_{e}^{j} \cdot CC_{e} \right) + \left(\sum_{j=1}^{J} \sum_{f=1}^{F} OCP \cdot PT_{f}^{j} \cdot CP_{f} \right) + \left(\sum_{k=1}^{K} \sum_{p=1}^{P} OCA \cdot AD_{p}^{k} \cdot CA_{p} \right) \\ + \left(\sum_{k=1}^{K} \sum_{r=1}^{R} OCG \cdot G_{r}^{k} \cdot CG_{r} \right) \\ + \left(\sum_{k=1}^{K} \sum_{q=1}^{Q} OCHPA_{t} \cdot CHPA_{q}^{k} \cdot CCHPA_{q} \right) + \left(\sum_{k=1}^{K} \sum_{v=1}^{V} OCHPG_{t} \cdot CHPG_{v}^{k} \cdot CCHPG_{v} \right) \end{array} \right] \right] \\
& - \left[\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{m=1}^{M} \sum_{b=1}^{B} UBC_{b} \cdot \left(SC_{mb}^{ij} + SP_{mb}^{ij} \right) \right] - \left(\sum_{k=1}^{K} W^{k} \cdot WC \right)
\end{aligned} \tag{8}
$$

The following equation represents the second objective function.

$$
\begin{aligned}
Min\ z = & \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{m=1}^{M} \sum_{b=1}^{B} ceT1_{mb}^{ij} + \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{b=1}^{B} ceT2_{mb}^{jk} + \sum_{j=1}^{J} \sum_{b=1}^{B} ceP_{b}^{j} \\
& + \sum_{k=1}^{K} \left(ceA^{k} + ceG^{k} + ceCHPA^{k} + ceCHPG^{k} \right)
\end{aligned} \tag{9}
$$

2.2. Constraints

Material flow balance and conversion constraints: This constraint set ensures the material flow balance between biomass, facility, plant and demand locations, restricts the biomass procurement amount from a supply region by the total available biomass in that region, calculates the production amounts in the bioenergy plants using the biomass to bioenergy conversion rates and ensures that all the bioenergy demand is met in the demand nodes.

$$
\sum_{j=1}^{J} \sum_{m=1}^{M} SC_{mb}^{ij} + SP_{mb}^{ij} \leq BS_{b}^{i} \quad \forall i, \forall b \tag{10}
$$

$$
\left(\sum_{i=1}^{I} \sum_{m=1}^{M} SP_{mb}^{ij} \cdot d_{b} \right) + \sum_{i=1}^{I} \sum_{m=1}^{M} SC_{mb}^{ij} = \sum_{m=1}^{M} \sum_{k=1}^{K} SA_{mb}^{jk} + SG_{mb}^{jk} \quad \forall j, \forall b \tag{11}
$$

$$\sum_{j=1}^{J}\sum_{m=1}^{M}\sum_{b=1}^{B} SA_{mb}^{jk} \cdot g1_b = OUTB^k \quad \forall k, \forall t \tag{12}$$

$$OUTB^k \cdot (1-a) \geq \sum_{l=1}^{L}\sum_{m=1}^{M} DB_m^{kl} \quad \forall k \tag{13}$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M} DB_m^{kl} \geq DEMB^l \quad \forall l \tag{14}$$

$$OUTB^k \cdot a = CGA^k \quad \forall k \tag{15}$$

$$\sum_{j=1}^{J}\sum_{m=1}^{M}\sum_{b=1}^{B} SG_{mb}^{jk} \cdot g2_b = OUTS^k \quad \forall k \tag{16}$$

$$(e1 \cdot CGA^k) + (e2 \cdot CGG^k) = OUTE^k \ \forall k \tag{17}$$

$$\sum_{k=1}^{K} OUTE^k \geq DEME_t^l \quad \forall l \tag{18}$$

$$(h1 \cdot CGA^k) + (h2 \cdot CGG^k) = OUTH^k \ \forall k \tag{19}$$

$$OUTH^k \geq \sum_{l=1}^{L} SH^{kl} \quad \forall k \tag{20}$$

$$\sum_{k=1}^{K} SH^{kl} \geq DEMH^l \quad \forall l \tag{21}$$

Capacity constraints: This constraint set limits the capacities of the collection centers by the maximum capacity. Also they limit the transportation and production amounts to the maximum capacity of the corresponding capacity levels of plants/facilities.

$$\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{b=1}^{B} SC_{mb}^{ij} = CapCO^j \quad \forall j \tag{22}$$

$$CapCO^j \leq MaxC * CO^j \quad \forall j \tag{23}$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{b=1}^{B} SP_{mb}^{ij} \leq \sum_{f=1}^{F} CP_f \cdot PT_f^j \quad \forall j \tag{24}$$

$$\sum_{j=1}^{I}\sum_{m=1}^{M}\sum_{b=1}^{B} SA_{mb}^{jk} \leq \sum_{p=1}^{P} CA_p \cdot AD_p^k \quad \forall k \tag{25}$$

$$\sum_{j=1}^{I}\sum_{m=1}^{M}\sum_{b=1}^{B} SG_{mb}^{jk} \leq \sum_{r=1}^{R} CG_r \cdot G_r^k \quad \forall k \tag{26}$$

$$CGA^k \cdot e \leq \sum_{q=1}^{Q} CCHPA_q \cdot CHPA_q^k \quad \forall k \tag{27}$$

$$CGG^k \cdot e \leq \sum_{v=1}^{V} CCHPG_v \cdot CHPG_v^k \quad \forall k \tag{28}$$

Construction constraints: This constraint set ensures that there must be a CHP unit if there is G plant in a location whereas there may not be a CHP unit in an AD plant and there must be only one type of CHP in the plants.

$$\sum_{q=1}^{Q} CHPA_q^k + \sum_{v=1}^{V} CHPG_v^k \leq 1 \quad \forall k \tag{29}$$

$$\sum_{q=1}^{Q} CHPA_q^k \leq \sum_{p=1}^{P} AD_p^k \quad \forall k \tag{30}$$

$$\sum_{v=1}^{V} CHPG_v^k = \sum_{r=1}^{R} G_r^k \quad \forall k \tag{31}$$

Transportation capacity constraints: This constraint set limits the transportation amounts by the capacities regarding to each transportation mode.

$$SC_{mb}^{ij} \leq C1T_b^m \cdot TA_b^m \cdot TM1_{tmb}^{ij} \quad \forall i, \forall j, \forall m, \forall b \tag{32}$$

$$SP_{mb}^{ij} \leq C1T_b^m \cdot TA_b^m \cdot TM1_{tmb}^{ij} \quad \forall i, \forall j, \forall m, \forall b \tag{33}$$

$$SA_{mb}^{jk} \leq C1T_b^m \cdot TA_b^m \cdot TM2_{mb}^{jk} \quad \forall j, \forall k, \forall m, \forall b \tag{34}$$

$$SG_{mb}^{jk} \leq C1T_b^m \cdot TA_b^m \cdot TM2_{tmb}^{jk} \quad \forall j, \forall k, \forall m, \forall b \tag{35}$$

Carbon emission constraints: This constraint set computes the amount of GHG emissions associated to the transportation and production activities in the supply chain.

$$ceT1_{mb}^{ij} = \left\lfloor c_{mb} \cdot d1^{ij} \cdot \left(SC_{mb}^{ij} + SP_{mb}^{ij} \right) \right\rfloor \quad \forall i, \forall j, \forall m, \forall b \tag{36}$$

$$ceT2_{mb}^{jk} = \left\lfloor c_{mb} \cdot d2^{jk} \cdot \left(SA_{mb}^{jk} + SG_{mb}^{jk} \right) \right\rfloor \quad \forall j, \forall k, \forall m, \forall b \tag{37}$$

$$ceP_b^j = \left\lfloor cPT_b \cdot \sum_{i=1}^{I} \sum_{m=1}^{M} SP_{mb}^{ij} \right\rfloor \quad \forall j, \forall b \tag{38}$$

$$ceA^{\kappa} = cA \cdot OUTB^{\kappa} \quad \forall k \tag{39}$$

$$ceG^{\kappa} = cG \cdot OUTS^{\kappa} \quad \forall k \tag{40}$$

$$ceCHPA^k = cCHPA \cdot e1 \cdot CGA^k \tag{41}$$

$$ceCHPG^k = cCHPG \cdot e2 \cdot CGG^k \tag{42}$$

Total solid content constraint: This constraint assures that the total solid content of the mixture of biomass slurry in each bioenergy plant must be between the technical limits to ensure an efficient fermentation process in the digesters. The constraint also determines the amount of water required to satisfy the total solid content limits.

$$MinTS \leq \frac{\sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{m=1}^{M} TS_b * SA_{jkmb}}{\left(\sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{m=1}^{M} SA_{jkmb} \right) + W^k} \leq MaxTS \quad \forall k \tag{43}$$

4. Case study

To explore the viability of the proposed model, computational experiments are performed on a case study in West Midlands, UK. The Nomenclature of territorial units for statistics (NUTS) is a geographical classification that subdivides territories in the UK into regions at three different levels from larger to smaller territorial units (i.e. NUTS 1, 2 and 3 respectively). West Midlands is a NUTS 2 level region and it is divided into seven NUTS 3 level territorial areas. The proposed model is applied to NUTS 3 regions in the West Midlands (Birmingham, Coventry, Solihull, Sandwell, Walsall, Wolverhampton and Dudley) to design a comprehensive bioenergy supply chain network. The abovementioned regions are considered as potential sites for the supply of biomass, bioenergy plants and biomass collection and pretreatment facilities as well as demand nodes in the model. The map of the case study region is depicted in Figure 2.

Fig. 2. Case study region map (http://www.yourvelvetevolution.com/wp-content/uploads/2015/01/West-Midlands.png)

Biomass sources and bioenergy demand: The proposed model includes four types of waste biomass to be transformed into energy: cattle manure, laying chicken manure, broiler chicken manure and waste wood. Data about the waste biomass potential from husbandry in the West Midlands is gathered from UK Department for Environment, Food & Rural Affairs (DEFRA). Wood waste generated as part of the manufacturing processes and when a wood product is disposed of at end life are considered in the study. In this regard, data on packaging, industrial, construction, demolition and municipal wood waste potential in the West Midlands came from Tolvik Ltd (2009). We consider meeting the corresponding biogas, electricity and heat demands in a particular area in each of the NUTS 3 regions in West Midlands. The numbers of addresses in the area considered in each region are given in Table 2. Data on the demands came from DECC.

Table 2 – The numbers of addresses in the area considered in each region

Demand Node	**Number of addresses**
1. Birmingham	960 Residential
2. Solihull	180 Retail
3. Coventry	320 Residential
4. Dudley	1 Industrial user
5. Sandwell	1 Education
6. Walsall	6 Commercial Offices
7. Wolverhampton	39 Retail

Transportation: Given the regional focus in our case study we only considered road transport as the preferred mode and specifically two types: transportation by a single trailer truck with a load capacity of 32 tons and a single trailer truck with a load capacity of 24 tons with average travelling speed of 60 km/hr. Waste biomass with high solid content (laying chicken manure and woodchip) is considered as solid biomass, while feedstock with low total solid content (cattle manure and broiler chicken manure) is considered as liquid/semi-solid biomass. Biomass sources are transported by trucks with the cost of €0.045/t-km for solid biomass and €0.05/t-km for liquid/semi-solid biomass. The data is assumed to be the same for all NUTS 3 level regions.

Bioenergy plants and facilities: To ensure the efficiency of fermentation process, the total solid content of biomass slurry in the digester should vary between 7% and 12%. The electrical and thermal efficiency of the cogeneration units are taken as 40% and 40%. The conversion rate of wood to woodchip is assumed to be 0.8. Although a parameter representing “Percentage of biogas to be converted to energy” in AD plants (a) is included in our model, we assume in this case study that only biogas is produced in AD whereas G plants are operated to produce only electrical and thermal energy. Two capacity levels are considered for the pretreatment facilities, plants and CHP units. These capacity levels reported in Table 3.

Table 3 - Capacity levels of the plants

Capacity Level	Total biomass capacity of G plants (t/month)	Installed capacity of cogeneration unit in G plant (kWe)	Total biomass capacity of AD plants (t/month)	Installed capacity of cogeneration unit in AD plant (kWe)	Total biomass capacity of PT facilities (t/month)
1	1750	4500	9000	2750	3000
2	2250	6000	10000	3250	5000

Economics: The generated electrical energy, thermal energy and biogas are assumed to be fed into the national electricity grid, on-site heating system and natural gas pipeline network. The energy prices are important sources of uncertainty as they continually fluctuates. However in this study we considered average values as our model is deterministic. The related average prices are gathered from DECC, which are €0.124/kWh, €0.07/kWh and €0.16/m3. It is assumed that waste biomass is supplied at no charge by the local farms, companies and municipalities. A gate fee is not considered in this study. Monthly discount rate is taken as 0.006 and lifetime of the plants are 20 years. The length of the time period used in our computational experiments is one month

We obtain the data on plant investment costs corresponding to different plant capacity levels by a survey on AD and G plant installations around the UK. DECC (2008) and Do et al. (2014) are also utilized to gather the data. The investment costs per kilowatt of installed power are taken into consideration in a manner that they decrease with higher capacities because of economies of scale. The investment costs per kilowatt of installed power depending on capacity levels and counties are reported in Table 4. Annual operational costs of plants and storages are taken as 5% of investment costs. This percentage is also obtained by a survey on biogas plant installations and storages and by utilizing professional expert opinion. It should be noted that, unit costs are computed considering monthly capacity of the facilities and plants.

Table 4 - Unit investment costs per installed capacity depending on capacity levels

Capacity Level	Unit investment cost of G plants (€/ton)	Unit investment cost of CHP unit in G plant (€/kWe)	Unit investment cost of AD plants (€/ton)	Unit investment cost of CHP unit in AD plant (€/kWe)	Unit investment cost of PT facilities(€/ton)
1	20000	800	1600	800	1000
2	18000	750	1500	750	750

GHG Emissions: Data on GHG emissions associated with transportation of biomass by trucks, woodchip production in pretreatment facilities and bioenergy production in plants (including conversion in CHP units) are gathered utilizing DECC (2014) and LCA tool SIMAPRO.

5. Results and discussion

This section presents and analyses the results of our computational experiments. The proposed model is programmed and solved using IBM ILOG CPLEX Optimization Studio (Version 12.2). The experiments were performed on an Intel Core Quad 2.66 GHz processor with 6 GB RAM on a 64-bit platform under Windows 7 environment. The large-scale MILP model is composed of 3025 constraints and 3474 variables (of which 861 are integer variables). The problem is solved by FGP taking the steps given in following sections.

Efficient extreme solutions: The developed multi objective MILP model (see Section 2) is solved as a single objective problem using each time only one objective and ignore the others to specify the efficient extreme solutions for each objective. Upper and lower bounds for total supply chain profit are €73617 and €-48071, for total GHG emissions are 751,5 tons CO_2 eq and 278,2 tons CO_2 eq, respectively. As the lower bound for the profit depicts the state of loss (under 0), it is taken as 0.

Membership functions: Formulations of linear membership functions for each fuzzy objective and fuzzy constraint are determined considering the upper and lower bounds and are represented by the following equations.

$$\mu_{Profit} = \begin{cases} 1 & ; \quad Profit > 73617 \\ \dfrac{Profit - 0}{73617 - 0} & ; \quad 0 < Profit \le 73617 \\ 0 & ; \quad Profit \le 0 \end{cases} \tag{44}$$

$$\mu_{GHG} = \begin{cases} 1 & ; \quad GHG\ emissions \le 278230 \\ \dfrac{751532 - GHG\ emissions}{751532 - 278230} & ; \quad 278230 < GHG\ emissions \le 751532 \\ 0 & ; \quad GHG\ emissions > 751532 \end{cases} \tag{45}$$

Fuzzy solution approaches: Considering the membership functions, the fuzzy model is transformed to a MILP model by introducing the auxiliary variable λ using Werners' "Fuzzy and" operator. The MILP problem corresponding to the fuzzy solution approaches are presented in the following.

$$\begin{aligned} &Maximize \quad && \lambda + [(1-\gamma)(w_{Profit}\lambda_1 + w_{GHG}\lambda_2)] \\ &Subject\ to && \mu_{Profit} \ge \lambda + \lambda_1 \\ & && \mu_{GHG} \ge \lambda + \lambda_2 \\ & && \lambda, \gamma \in [0,1] \end{aligned} \tag{46}$$

and other system constraints

Appendix 2 reports optimal solutions obtained by the modified version of Werners' "Fuzzy and" operator according to different γ (coefficient of compensation) values. At this stage, a sensitivity analysis is conducted to see the impact of the coefficient of compensation on the results. In real life decision problems, relative importance of the objectives assigned by the DMs may change according to DM or over time. To provide a broader decision spectrum to DMs, the solutions are obtained by using two different relative weight combinations for the objectives (W_{Profit}=0.8, W_{GHG}=0.2 and W_{Profit}=0.5, W_{GHG}=0.5) representing the scenarios that making profit is more important and both of the objectives are equally important for DM. There are some good fuzzy approaches in the literature to determine weights of the goals in fuzzy environment. Lai & Hwang (1994) can be referred for detailed explanation of these approaches. It should be noted that, each solution result belongs to a supply chain configuration option. Optimal configuration can be chosen among the options according to the DM's preferences related to supply chain performance indicators.

The results provide a broad perspective to DMs. As stated before, any solution alternative can be selected as the best one concerning the priorities of the DM on different supply chain performance indicators. In this regard, tradeoffs among the solution alternatives need to be considered.

As reported in Appendix 2, if profitability is more important than other supply chain performance indicators, the sixth alternative (γ=0.8) with greatest value for profit can be treated as the best solution. In this case, total profit of the supply chain is €73617. If the amount of GHG emissions is more important for the DM, all of the alternatives except the first, second and fourth one can be preferred as all the other configuration options . If the DM prefer the weight structure of W_{Profit}=0.8 and W_{GHG}=0.2, comparison of the results with γ=0.8 and γ=0.2 reveals that a 0.22% decrease in total GHG emissions can be attained with a 65% decrease in total profit. If the weight structure of W_{Profit}=0.5 and W_{GHG}=0.5 is chosen by the DM, by changing the γ value from 0.8 to 0.2 an 21.5% decrease in total GHG emissions can be attained with a 64% decrease in total profit.

Comparing the results given in Appendix 2, let's suppose that the DMs consider the solution obtained by the model with the following weight structure; W_{Profit}=0.5 and W_{GHG}=0.5 and γ=0.8 (fourth option) as the preferred solution where the total profit is €72738 and the amount of total GHG emissions is 746524 kg CO2 eq. In this situation, the optimum configuration determined by the model suggests the construction of one AD plant (1. capacity level) and one G plant (2. capacity level) with a CHP unit (2. capacity level) in Birmingham and Solihull, respectively. In addition, there are three collection centers in Birmingham, Solihull and Sandwell with capacities of 3600, 3769.9, 3.744 tons, respectively. One pretreatment facility is determined to be located in Solihull with 1. capacity level as well.

Appendix 3 and 4 describe results about the biomass flow pattern between regions prescribed by the optimization model for the above mentioned scenario. It can be observed from the tables in Appendix 3 and 4 that, the model suggests transportation of biomass by 32 ton truck rather than truck with 24 ton capacity.

6. Conclusions

The aim of this study was to design an effective biomass to energy supply chain network by considering economic and environmental objectives. The proposed multi-objective MILP model helps determining at the strategic level, the numbers, locations and capacities of the bioenergy plants and collection and pretreatment facilities, but also at the tactical level it supports decision taking with regards to biomass supply, bioenergy production and distribution. Although the problem under consideration is modeled with problem specific constraints, the proposed model is generic in its structure and can be tailored to handle bioenergy a range of supply chain design problems in various regions with different types of feedstock and transportation options. The results of the case study reveal that the proposed model and solution algorithm can effectively be used in practice, to obtain the economic and environmental benefits from biomass based energy supply chain design. The government and private investors can employ the proposed model and solution algorithm to design the most profitable and environment friendly supply chain to meet energy demand of a specific region. The model also facilitates identifying policies to support a viable, profitable and eco-friendly bioenergy industry for governmental units. The methodology can also be applied at the company level, for strategic planning of its activities.

The model can be extended to capture the stochastic nature of biomass supply and technology development by converting it to a Stochastic Programming model. It can also be extended with regards to transportation, which is one of the most important activities in a bioenergy supply chain both in terms of total cost and GHG emissions. More specifically, the model can be used to assist decision-making and selection of the most suitable modes of transport including combinations of intermodal transport. Of course as with every optimization model its applicability can be demonstrated further by using new and even more robust datasets. Including additional objectives in the proposed model may be another extension of this study. In this regard, other environmental objectives related to energy efficiency and land use as well as social objectives such as maximization of job creation or social acceptability of the energy conversion system, may be considered.

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Appendix 1. Notations and related descriptions for model indices, input parameters and decision variables

Indices	
i	*Biomass source sites*
j	*Candidate locations for collection and pretreatment facilities*
k	*Candidate locations for AD and G plants*
l	*Demand nodes*
m	*Transportation modes*
b	*Biomass types*
p	*Biomass capacity levels for AD plants*
r	*Biomass capacity levels for G plants*
e	*Biomass capacity levels for collection facilities*
f	*Biomass capacity levels for pretreatment facilities*
q	*Electrical energy production capacity levels of CHP in AD plants*
v	*Electrical energy production capacity levels of CHP in G plants*

Decision Variables	
1. Binary variables	
AD_p^k	*1 if an AD plant of capacity p is located at k, 0 otherwise*
G_r^k	*1 if a G plant of capacity r is located at k, 0 otherwise*
CO_e^j	*1 if a CO facility of capacity e is located at j, 0 otherwise*
PT_f^j	*1 if a PT facility of capacity f is located at j, 0 otherwise*
$CHPA_q^k$	*1 if a CHP of capacity q is located in an AD plant at k, 0 otherwise*
$CHPG_v^k$	*1 if a CHP of capacity v is located in a G plant at k, 0 otherwise*
$TM1_{mb}^{ij}$	*1 if biomass b is transported from biomass source site i to facility j by transportation mode m, 0 otherwise*
$TM2_{mb}^{jk}$	*1 if biomass b is transported from facility j to plant k by transportation mode m, 0 otherwise*
2. Positive variables	
SC_{mb}^{ij}	*Amount of biomass b shipped from biomass source site i to CO facility j by transportation mode m (ton)*
SP_{mb}^{ij}	*Amount of biomass b shipped from biomass source site i to PT facility j by transportation mode m (ton)*
SA_{mb}^{jk}	*Amount of biomass b shipped from facility j to AD plant k by transportation mode m (ton)*
SG_{mb}^{jk}	*Amount of biomass b shipped from facility j to G plant k by transportation mode m (ton)*
DB^{kl}	*Amount of biogas shipped from AD plant k to demand node l by transportation mode m (m^3)*
SH^{kl}	*Amount of heat produced in plant k to meet demand of node l (kWh)*
SE^{kl}	*Amount of electricity produced in plant k to meet demand of node l (kWh)*
$OUTB^k$	*Amount of biogas produced at AD plant k (m^3)*
$OUTS^k$	*Amount of total syngas produced at G plant k (m^3)*

CGA^k	*Amount of biogas used to produce energy at AD plant k (m^3)*
$OUTE^k$	*Amount of electricity produced at plant k (kWh)*
$OUTH^k$	*Amount of heat produced at plant k (kWh)*
$CapCO^j$	*Capacity of CO facility at location j (ton)*
W^k	*Amount of water consumed at AD plant k (ton)*
$ceT1_{mb}^{ij}$	*Amount of GHG emissions associated with transportation of biomass b from biomass source site i to facility j by transportation mode m (kg CO2 eq)*
$ceT2_{mb}^{jk}$	*Amount of GHG emissions associated with transportation of biomass b from facility j to plant k by transportation mode m (kg CO_2 eq)*
ceP_b^j	*Amount of GHG emissions associated with treatment of biomass b at PT facility j (kg CO_2 eq)*
ceA^k	*Amount of GHG emissions associated with production of biogas at AD plant k t (kg CO_2 eq)*
ceG^k	*Amount of GHG emissions associated with production of syngas at G plant k (kg CO_2 eq)*
$ceCHPA^k$	*Amount of GHG emissions associated with production of energy by a CHP in G plant k (kg CO_2 eq)*
$ceCHPG^k$	*Amount of GHG emissions associated with production of energy by a CHP in AD plant k (kg CO_2 eq)*

Parameters	
1.Biomass supply and product demand	
$DEMB^l$	*Amount of biogas demand at demand node l (m^3)*
$DEME^l$	*Amount of electricity demand at demand node l (kWh)*
$DEMH^l$	*Amount of heat demand at demand node l (kWh)*
BS_b^i	*Amount of available biomass b at biomass source site i (ton)*
2. Capacities	
CA_p	*Biomass capacity of AD plant of capacity level p(ton)*
CG_r	*Biomass capacity of G plant of capacity level r (ton)*
$CCHPA_q$	*Installed electrical capacity of CHP in AD plant of capacity level q (kWe)*
$CCHPG_v$	*Installed electrical capacity of CHP in G plant of capacity level v (kWth)*
CP_f	*Biomass capacity of PT facility of capacity level f (ton)*
$C1T_{mb}$	*Maximum capacity of transportation mode m for biomass b (ton)*
$C2T_{mu}$	*Maximum capacity of transportation mode m for product u (ton)*

$MaxC$	*Maximum capacity of CO (ton)*
3. Costs and prices	
TCB_{bm}	*Unit transportation cost of biomass b transported by mode m (€/t-km)*
ICC	*Unit investment cost of CO facility (€/ton)*
ICP	*Unit investment cost of PT facility (€/ton)*
ICA	*Unit investment cost of AD plant (€/ton)*
ICG	*Unit investment cost of G plant (€/ton)*
$ICHPA$	*Unit investment cost of CHP in AD plant (€/kWh)*
$ICHPG$	*Unit investment cost of CHP in G plant (€/kWh)*
OCC	*Unit operational cost of CO facility (€/ton)*
OCP	*Unit operational cost of PT facility (€/ton)*
OCA	*Unit operational cost of AD plant (€/ton)*
OCG	*Unit operational cost of G plant (€/ton)*
$OCHPA$	*Unit operational cost of CHP in AD plant (€/kWh)*
$OCHPG$	*Unit operational cost of CHP in G plant (€/kWh)*
UBC_b	*Unit cost of biomass b (€/ton)*
WC	*Unit cost of water (€/ton)*
PB	*Unit price of biogas* (€/m^3)
PE	*Unit price of electricity (€/kWh)*
PH	*Unit price of heat (€/kWh)*
4. Distances	
$d1^{ij}$	*Distance from biomass source site i to facility j (km)*
$d2^{jk}$	*Distance from facility j to plant k (km)*
$d3^{kl}$	*Distance from plant k to demand node l (km)*
5. Conversion rates	
d_b	*Conversion rate of biomass b in the pretreatment facilities (%)*
$g1_b$	*Conversion rate of biomass b to biogas in plants* (m^3/ton)
$e1$	*Biogas to electricity conversion rate* (kWh/m^3)
$e2$	*Syngas to electricity conversion rate* (kWh/m^3)
$h1$	*Biogas to heat conversion rate* (kWh/m^3)
$h2$	*Syngas to heat conversion rate* (kWh/m^3)
a	*Percentage of biogas to be converted to energy (%)*
6. Carbon Emissions	
c_m	*Variable GHG emissions per 1 ton of biomass b associated with transportation mode m (*kg

	CO_2 eq*)*
cPT	*Variable GHG emissions per 1 ton of biomass b associated with PT facility (*kg CO_2 eq*)*
cA	*Variable GHG emissions per 1 ton of biogas associated with AD plant (*kg CO_2 eq*)*
cG	*Variable GHG emissions per 1 ton of syngas associated with G plant (*kg CO_2 eq*)*
cCHPA	*Variable GHG emissions per 1 kWh of energy associated with CHP in G plant (*kg CO_2 eq*)*
cCHPG	*Variable GHG emissions per 1 kWh of energy associated with CHP in A plant (*kg CO_2 eq*)*
7. Other parameters	
TS_b	*Total solid content in biomass b (%)*
MaxTS	*Maximum total solid content of biomass slurry in digester (%)*
MinTS	*Minimum total solid content of biomass slurry in digester (%)*
DF	*Discounting factor*
TA_{mb}	*Availability of transportation mode m for shipment of biomass b*

Appendix 2. Optimal solutions obtained by the modified version of Werners' "Fuzzy and" operator according to different γ values and objective weights

γ	Overall Profit (€/month)	GHG Emissions (kg CO2 eq)	Locations, and Capacities of AD Plants	Locations and Capacities of G Plants and CHP units	Locations, Numbers and Capacities of Collection Facilities	Locations, and Capacities of Pretreatment Facilities
W_{Profit}=0.8 and W_{GHG}=0.2						
0.8	73617	751529	Location: Solihull Capacity: 1. level	(G)Location: Solihull Capacity: 2. level (CHP) Number: 1 Capacity: 2. level	Number: 3 Location:Birmingham, Solihull, Sandwell Capacity: 3600, 3769.9, 3.744	Location: Solihull Capacity: 1. level
0.5	72688	746641	Location: Birmingham Capacity: 1. level	(G)Location: Birmingham Capacity: 2. level (CHP) Number: 1 Capacity: 2. level	Number: 2 Location:Birmingham Solihull Capacity: 3729.9 3643.8	Location: Birmingham Capacity: 1. level
0.2	25757	585927	Location: Solihull Capacity: 1. level	(G)Location: Birmingham Capacity: 2. level (CHP) Number: 1 Capacity: 2. level	Number: 1 Location: Solihull Capacity: 5901.4	Location: Birmingham Capacity: 1. level
W_{Profit}=0.5 and W_{GHG}=0.5						
0.8	72738	746524	Location: Birmingham Capacity: 1. level	(G) Location: Solihull Capacity: 2. level (CHP) Number: 1 Capacity: 2. level	Number: 3 Location:Birmingham Solihull, Sandwell Capacity: 3600 3769.9 3.744	Location: Solihull Capacity: 1. level
0.5	25758	585926	Location: Solihull Capacity: 1. level	(G) Location: Solihull Capacity: 2. level (CHP) Number: 1 Capacity: 2. level	Number: 2 Location: Solihull, Sandwell Capacity: 5899.9 1.4976	Location: Solihull Capacity: 1. level
0.2	25758	585927	Location: Solihull Capacity: 1. level	(G) Location: Solihull Capacity: 2. level (CHP) Number: 1 Capacity: 2. level	Number: 2 Location: Birmingham, Solihull Capacity: 1.152 5900.2	Location: Solihull Capacity: 1. level

Appendix 3. Biomass flow pattern between facilities and plants

	AD and G Plant Location	
Facility Site	**Birmingham (AD)**	**Solihull (G)**
Birmingham	TM*: 32 ton truck, B: Cattle manure, A: 3600 t	
Solihull	TM: 32 ton truck, B: Cattle manure, A: 3600 t TM: 32 ton truck, B: Broiler manure, A: 68 t TM: 24 ton truck, B: Layer manure, A: 101 t	TM: 32 ton truck, B: Woodchip, A: 2160 t
Sandwell	TM: 32 ton truck, B: Broiler manure, A: 1.49 t TM: 32 ton truck, B: Layer manure, A: 2.25 t	

Appendix 4. Biomass flow pattern between biomass source sites and facilities

	Collection and Pretreatment Center Location		
Biomass Source Site	**Birmingham (Only Collection-CO)**	**Solihull (Collection-CO and Pretreatment-PT)**	**Sandwell (Only Collection-CO)**
Birmingham	TM: 24 ton truck, B: Cattle manure, A: 488t	CO TM: 32 ton truck, B: Broiler manure, A: 23t TM: 32 ton truck, B: Layer manure, A: 34t	
Solihull	TM: 32 ton truck, B: Cattle manure, A: 1621t	CO TM: 32 ton truck, B: Cattle manure, A: 1200t TM: 24 ton truck, B: Cattle manure, A: 2400t TM: 32 ton truck, B: Broiler manure, A: 43t TM: 24 ton truck, B: Layer manure, A: 65t PT TM: 32 ton truck, B: Woodchip, A: 2700t	
Coventry	TM: 32 ton truck, B: Cattle manure, A: 871t	CO TM: 32 ton truck, : Broiler manure, A: 0.11t TM: 32 ton truck, B: Layer manure, A: 0.17t	
Dudley	TM: 32 ton truck, B: Cattle manure, A: 198t		TM: 32 ton truck, B: Broiler manure, A: 0.34 t TM: 32 ton truck, B: Layer manure, A: 0.52 t
Sandwell	TM: 32 ton truck, B: Cattle manure, A: 10t	CO TM: 32 ton truck, B: Broiler manure, A: 0.35t TM: 32 ton truck, B: Layer manure, A: 0.52 t	
Walsall	TM: 32 ton truck, B: Cattle manure, A: 285t	CO TM: 32 ton truck, B: Broiler manure, A: 0.7t TM: 32 ton truck, B: Layer manure, A: 1.05t	
Wolverhampton	TM: 32 ton truck, B: Cattle manure, A: 125t		TM: 32 ton truck, B: Broiler manure, A: 1.15 t TM: 32 ton truck, B: Layer manure, A: 1.73 t

*TM: Transportation Mode

RESILIENCE ANALYSIS OF DIFFERENT SUPPLY CONTRACTS USING SIMULATION

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Abstract
In today's competitive and dynamic environment, resilience in supply chains has become increasingly important for organizations to respond effectively to uncertainties and disruptions. The sourcing concept and supplier contract which provides the limited flexibility to the buyer play an important role to increase the resilience. In this context, the main objective of this paper is to analyze the impact of different supply contracts on the performance of supply chain in terms of resilience and fill rate. Numerically, we demonstrate the effectiveness of flexible supply contracts by using simulation approach.
Keywords: Simulation; Resilience; Flexible supply contract

Introduction

Companies operating in today's business environment face various uncertainties that make it difficult to operate successfully as supply chain disruptions are occurring regularly. At the same time, the local for local marketing strategy shifted away to modern value chains, which span the entire globe. The increasing competitive pressure in modern business environments has forced companies to use global outsourcing (Aksoy & Öztürk , 2012). Global sourcing and offshore manufacturing can be identified as a driver of cost saving decisions. The access of cheap labor and raw materials, better financing opportunities, larger product markets, and the attraction of foreign capital are key factors to be successful (Manuj & Mentzer, 2008). However, the opportunities created by the globalization of supply chains are often accompanied by new challenges. As supply chains become more global, they are becoming more vulnerable to business disruptions, and hence, they are usually slow to respond to changes (Tang & Tomlin, 2008). As the network extends over the entire globe, the amount of links interconnecting a wide network of enterprises is growing numerously. These links in the network are prone to increase the possibility for supply chain disruptions resulting from bankruptcies, breakdowns, political changes, and disasters (Manuj & Mentzer, 2008). Apart from increased use of outsourcing, there have been large natural disasters that have the potential to severely affect the continuity of a supply chain (Christopher & Peck, 2004). Furthermore, today's companies increasingly face with uncertainties, both internal and external (Angkiriwang, et al., 2014). As a result, there is a need for enterprises to have effective management of uncertainty and disruptions, so that they can survive in a rapidly changing competitive environment and succeed their strategies under uncertain conditions (Singhal, et al., 2011).

New risks, particularly the financial crisis and supplier bankruptcies, but also plant fires, transportation, breakdown, terrorist attacks, natural disasters (tsunamis, hurricanes), have a huge effect on the supply chain performance. An excellent example that shows how an enterprise suffers from a significant disruption is Ericsson's crisis in 2000: a fire broke out at Ericsson chip supplier plant leading to a production standstill of 2 weeks that finally caused an estimated loss of 400 Million Dollars because Ericsson had no backup sources. Similarly, Toyota was forced to shut down 18 plants for almost two weeks because of the fire in 1997 at Toyota's brake valve supplier. The costs caused by the disruption were an estimated $40 million per day (Norrman & Jansson, 2004). The examples mentioned above demonstrate that even small incidents can have a severe impact on the whole supply chain. The challenge in risk management today is to avoid such incidents or reduce their negative impacts.

A major part of every manufacturing and distribution activity is to ensure a smooth supply of raw materials and components needed to produce and assemble the final product in a cost-effective manner. Hence, the performance of supply chain management depends greatly on the purchasing and sourcing functions (Park, et al., 2010). Sourcing and purchasing play an important role in the presence of several types of uncertainties in supply and demand (Cheng, et al., 2011). An effective sourcing strategy helps the firm in minimizing purchasing risk and maximizing the performance of the firm. Sourcing is defined as "the management of the company's external resources in such a way that the supply of all goods, services, capabilities and knowledge which are necessary for running, maintaining, and managing the company's primary and support activities is secured at the most favorable conditions" (Van Weele, 2014). In relation to sourcing strategy, supplier selection has become a vital issue for many firms. Selecting the right suppliers makes a significant difference to an organization's future to reduce operational costs and improves corporate competitiveness (Zeydan, et al., 2011). For many years, price is used as a single criterion for the supplier selection process. However, many firms have been experienced that the sole emphasis on price as a single criterion is inefficient. For this reason, the attention has been shifted to more comprehensive multi-criteria decision making approaches that involve both quantitative and qualitative factors. Due to environmental, social, and political factors added to the traditional factors such as quality and delivery, decision criteria have become increasingly complex. Moreover, the increasing length and dynamic relationships between today's supply chain members add a new level of complexity to outsourcing. On the other hands, suppliers have been considered as inevitable sources of external risks in modern supply chains (Rajesh & Ravi, 2015). Supply uncertainties caused by these risks include component availability and purchasing price. It has been noted that the ability to cope with risks will determine supply chain performance. In supply chain systems, the main aim is to avoid and minimize the negative impacts of disturbances. Thus, the capability to prevent, protect against, respond to, and recover from a disturbance is vital for the supply chain success.

In particular, resilience has been used as important criteria to cope with such major supply chain disruptions and disaster. Instead of making high investments in eliminating every potential threat, it is much more appreciated to increase the resilience of the supply chain to adapt quickly and efficiently to changes in the environment. Resilience is defined as the ability of the system to return to its original state or a better one after being disturbed (Christopher & Peck, 2004). Building a resilient supply chain is related to development of responsiveness capabilities through flexibility and redundancy (Rice & Caniato, 2003). Recent studies found out that organizations with higher levels of flexibility are more capable of responding to unexpected events compared to inflexible supply chains (Swafford, et al., 2006). However flexibility comes along with an increase in costs in most cases as it increases the ability to adapt to changes. Thus, a match between flexibility and uncertainty has to be found in order to create a cost-effective configuration (Merschmann & Thonemann, 2011). This match is difficult to find in the first place as companies are struggling to determine the consequences of uncertainty and therefore the required degree of flexibility. Sourcing decisions in such a turbulent and dynamic environment are one of the most critical components of resilient and flexible supply chain. Thus, there is a need to integrate the resilience concept in the sourcing strategies.

According to Tang and Tomlin (2008), a flexible supply strategy through flexible supply contracts can play an important role in managing uncertainties and can be implemented to reduce supply chain risks. The purpose of a flexible supply contracts between a buyer and a supplier is to assist both of them in facing the uncertainty that is associated with the external demand (Ben-Tal, et al., 2005). However, this flexibility may come at some cost to the supplier, while it benefits the buyer. Therefore, a supplier will usually provide the limited flexibility or may offer prices based on the level of flexibility desired by the buyer (Barnes-Schuster, et al., 2002). Supply strategy and supply chain resilience are inherently intertwined. Their interactions gain a special significance for the managerial issues faced to define flexibility to different aspects of supply contracts. Besides, the behavior of the parties, risks imposed on them, and the resulting efficiencies are affected by different supply contracts (Bassok & Anupindi, 2008). From a managerial perspective, the flexible supply strategy is primarily interested in answers to the following questions: (i) How much flexibility of any given supply contract is sufficient? (ii) What is the value of an additional flexibility? (iii) What is the impact of various types of contracts on the supply chain resilience? Despite the increasing number of papers published on supply contracts, there has been little attention to the relationship between supply contracts and the resilience. Other research gap is that there has been no commonly accepted way to measure resilience of a supply chain.

In this paper, we investigate the impact of flexible supply contracts on the resilience of supply chain and evaluate the cost and resilience trade-off with in an uncertain environment by using discrete-event simulation approach. To illustrate this trade-off, seven case studies with different sourcing concepts and contract parameters are presented.

Supply Chain Resilience

The high number of sources of complexity exposes the network to an increasing level of uncertainty, and the uncertainty level exposes the network to numerous kinds of events creating a potential for unpredictable disruptions (Güller, et al., 2015). The occurrence of these events is usually random and has a probability of occurrence because not every future event or circumstance can be predicted. Even if the best forecasting methods are used, there will always be a certain degree of uncertainty. Zsidisin (2003) gives a suitable definition for the term "risk" in the supply chain context as "the potential occurrence of an incident associated with inbound supply from individual supplier failures or the supply market, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety". Managing uncertainties which create risks is always a challenge that requires the ability to survive and adapt in the face of turbulent change. Hence, risk management has become an essential part of management decision and control in supply chains. Other way to respond to such major supply chain disruptions is to build a resilient supply chain. In the supply chain literature, the resilience is essentially defined as the ability of a system to return to its original state or move to a new, more desirable state after being disturbed (Christopher & Peck, 2004). More recently, Ponomarov and Holcomb (2009) define resilience as "the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at desired levels of connectedness and control over structure and function". In contrast to prior perception, their definition includes the aspect of preparation. According to Klibi (2010), the concept of resilience also implies the avoidance of threatening disturbances. From the above definitions and summary presented in Table 1, there is no single consensus on the exact definition of the term 'resilience'. As some researchers define resilience as an aim to be reached by the overall system, the others accept resilience as an inherent ability within the supply network. Some describe resilience as both an inherent ability and a dynamic capability of the overall system (Perera & Bell, 2015). In this research, we use the definition of Christopher & Peck for supply chain resilience.

Table 1 – Core statements of the resilience definitions from several researchers

Authors	*Core statement of resilience definition*
(Christopher & Peck, 2004)	*Return to an original or more desirable state after disturbance*
(Jüttner & Maklan, 2011)	*Recover more effectively than others after risk event*
(Ponomarov & Holcomb, 2009)	*Prepare, respond and recover from unexpected events*
(Klibi, et al., 2010)	*Avoid disruptions and recover quickly*
(Ponis & Koronis, 2012)	*Anticipating, responding and maintaining control*
(Ates & Bittici, 2011)	*Survive, adapt and sustain turbulent change*

In the supply chain literature, several terms are linked with resilience, such as, agility, flexibility, and robustness. These terms either complement the topic of resilience or are used interchangeably with it. For example, some researchers argue that robustness is part of a successful implementation of resilience, whereas others state that these two terms represent two different concepts. Christopher & Peck (2004) and Mandal (2012) state that resilience and robustness are terms used interchangeably in practice. A robust system has the ability to absorb a disturbance while retaining the same previous state whereas a resilient system has the ability to adapt and achieve a new stable state (Asbjørnslett, 2008). This leads to the conclusion that robustness may be desirable, but is not synonymous with a resilient supply chain. Sheffi (2004) emphasizes that supply chain agility is the ability to respond to unanticipated changes. According to Swafford et al. (2006) , agility is defined as the supply chain's capability to respond quickly to short-term changes in demand (or supply) and environment. Most research articles of the existing literature claim that speed and flexibility are two important components of the supply chain agility. The concepts of flexibility and agility are therefore tightly coupled with supply chain resilience (Güller, et al., 2015). Wieland and Wallenburg (2013) define the resilience with two dimension; agility, resulting from visibility and speed, and robustness, resulting from anticipation and preparedness. Christopher and Peck (2004) define agility as the third element of supply chain resilience. According to Longo and Ören (2008), the most important elements affecting supply chain resilience are: flexibility, agility, velocity, visibility and redundancy. Based on the literature review, Lotfi et al. (2013) illustrate some overlapping and non-overlapping practices/initiatives across robustness, agility and resilience. Consequently, resilience can be achieved through robustness, flexibility and agility. In the context of robustness redundant capacity that may or may not be used is installed. It is additional capacity that would be used to replace the capacity loss caused by a disruption. In this regard, flexibility entails redeploying previously committed capacity (Rice & Caniato, 2003). On the other hand, instead of being prepared for every situation by creating a robust supply chain, it is much more appreciated to increase the flexibility of the supply chain to adapt quickly and efficiently to changes.

One challenge question in supply chain management is how to assess the resilience. The process of a disruption can be categorized in different phases as it is illustrated in Figure 1. As disruptions may or may not occur, firms can take measures before and after an unforeseeable event in order to be resilient. Thus, according to Melnyk et al. (2014), actions that aim to avoid shocks or to be prepared for them, are referred to as “resistance capacity”, whereas “recovery capacity” is the ability to restore operations after a disruption occurred. The difference between the two elements of “resistance” is that one is referred to preventing disruptions entirely (avoidance) and the other to shorten the time between the start of a disruption and the beginning of the recovery process (containment). The recovery process in turn, consists of a “stabilization” phase and the “return” to a steady state performance. The length of stabilization is depending on the severity of the disruption. Ponomarov and Holcomb (2009) identify one more phase of supply chain resilience besides resistance and recovery, which is called response phase. During this phase, a supply chain develops the ability to learn and adapt in response to disturbances. This diagram helps to visualize the magnitude of disturbance impact on the system performance.

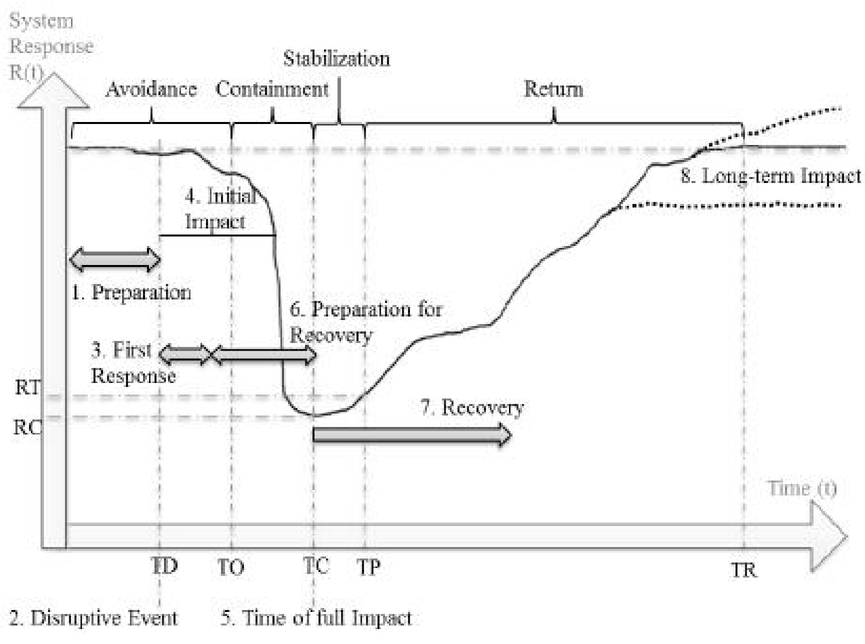

Figure 1 –Different phases of a disruption based on Sheffi (2004)

Flexible Supply Contracts

Recently, the risks in the supply chain associated with supplier failure have increased and the majority of supply chain disruptions occur often due to a supplier failure. Risks coming from the suppliers can be categorized as quantity risks and price risks. Both of these factors can cause extensive disruptions, which can lead to enormous profit loss in the short run and market share loss in the long run. Quantity risks can be caused by machine defects, mismatches between ordered and received quantities, and product defects, as well political decisions, political instability, natural disasters, and human errors (Lee, 2014). Price risks refer to unanticipated increases in acquisition costs resulting from price or from fluctuating exchange rates. It has been widely recognized that coordination between the supplier and the buyer can improve the overall performance under disruptions. Hence, supplier selection and supplier contract can be important factors for creating resilient supply chains. The process of supplier selection generally involves many different factors and criteria as illustrated in Figure 2. Resilience and risk reduction are only two factors among many others, such as quality and price. According to Christopher and Peck (2004), resilient suppliers are defined as suppliers who are able to provide good quality products at economy rates and flexible enough to accommodate demand fluctuations with shorter lead times. Figure 2 shows attributes considered for the selection of suppliers in a resilient supply chain. In this context, supply contract can be defined as an important tool to create a resilient supplier. Supply contracts coordinate materials and information flows between a supplier and a buyer. Different and often conflicting objectives can be accommodated through associating them with the right incentives (Tsay & Lovejoy, 1999).

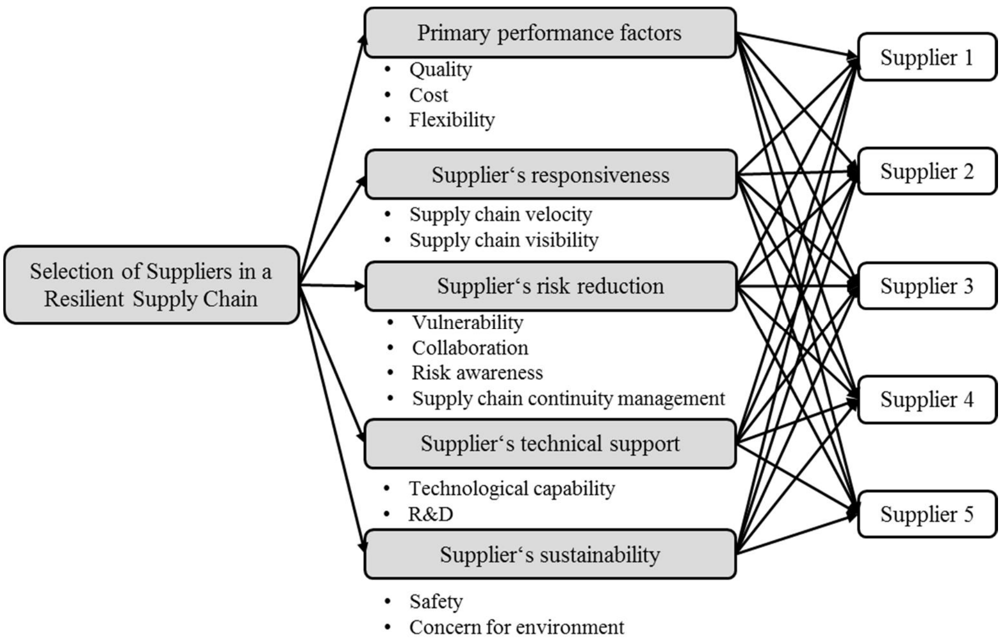

Figure 2 – Attributes for the selection of suppliers in a resilient supply chain (Rajesh & Ravi, 2015)

In general, pricing, minimum purchase commitments, quantity flexibility, buy backs or return policies, allocation rules, lead time and quality can be issued in such contracts (Hennet & Arda, 2008). A buy-back contract (return policy) is a commitment by the supplier to buy back unsold inventory of the goods at the end of the selling season so as to induce the buyer to order more from the supplier (Hou, et al., 2010). In this case the supplier charges the buyer a certain amount per unit. At the end of the period the retailer sells all the remaining units back to the supplier. Since the retailer should not profit from left over inventory, the price the supplier pays to get units back is lower than the price the retailer had to pay in the beginning. Quantity flexibility is an important characteristic in a supply contract that allows the buyer to adjust its order quantities to a later date and at a favorable price after an improved forecast of the customer demand becomes available (Sethi, et al., 2004). Another form of flexibility in supply contracts includes capacity reservation, when the supplier is obligated to cover any request that remains within the upside limits (Cheng, et al., 2011). For undertaking the risk of guaranteeing to deliver any order amount desired by the buyer up to a reserved fixed capacity, the buyer offers guaranteed payment by making an obligation to buy a certain unit of capacity every day. Even if the buyer does not fully utilize the reserved capacity, he will pay for it (Xu, 2006). Under all the different kinds of flexible supply contracts, the option contract has attracted extensive attention. Moreover, it was proven to be an effective way of coordination between manufacturer and supplier.

A common characteristic of option contracts is that the buyer may modify its ordered quantity to the supplier after realization of demand by paying and option premium (Gomez_Padilla & Mishina, 2009). The two possible versions of an option contract are the call option and the put option. Under such a call option contract, at the beginning of the planning horizon, the manufacturer places the order quantity Q with each unit the price p_0. In addition to an initial order, depending on prices provided by the supplier (p_c), the manufacturer can purchase options to obtain the flexibility of adjusting order quantity (q) later. This allows the manufacturing company to order additional units if market demand is more than its initial order, but the firm is not obliged to buy these optional units. If the manufacturer takes advantage of its option, the supplier has to deliver $Q + q$ units. Hence, this call option allows the existing practice of adding quantity flexibility to supply contracts (Cheng, et al., 2011). The put option contract is a generalization of a buy-back contract that allows the buyer to return unsold goods at a predetermined salvage price. In the put option model, the manufacturer places an order with quantity Q, similar to the call option model. Each of these units has a price of p_0. In addition, the buyer purchase q (put) option contracts at a price of (p_p). Any such contract gives the manufacturer the possibility to return a surplus product to the supplier after the contract period. Thus, the supplier produces Q units and is obliged to take up to q units back from the manufacturer.

Simulation Model and Description of Scenarios

In order to study how risk propagates through upstream supply and to assess how alternative policies influence the impact of these events, a computer based simulation model is built and exposed to disruption. The focal company is supplied with intermediate goods from one or more suppliers. The intermediate goods are converted into finished products by this focal firm. For each supply strategy, a scenario is developed. The supply strategies differ in the number of suppliers and the contract between suppliers and the focal company (see Table 2). At first four classes have been defined:

1. Single sourcing with standard contract
2. Multiple sourcing with standard contract
3. Multiple sourcing utilizing a flexible supply contract with call option
4. Multiple sourcing utilizing a flexible supply contract with put option

The last three classes of supply strategy have been subdivided into two subcategories. The first subcategory contains a supply chain with two suppliers of intermediate goods and the second subcategory consists of supply chains with three supplying firms. Hence, in total seven different scenarios are developed and simulated. The first scenario consists of the focal company, its *Customer*, and only one supplier. Since it is the only supplier and delivers a high volume of intermediate goods, the focal company is able to take advantage of economies of scale. This allows it to sell their semi-finished products at a low price. In scenario 1 absolutely no flexibility is designed into the supply chain. Under scenario 2, the focal company uses two suppliers and distributes necessary products among the suppliers. While *Supplier 1* always delivers 80 % of the ordered demand, *Supplier 2* delivers the remaining 20 % of the total order. Compared to scenario 1, *Supplier 1* cannot take as much advantage of economies of scale as before since the number of units *Supplier 1* sells to *the focal company* is reduced. This leads to an increase of the price per unit. *Supplier 2* can be seen as a smaller firm than *Supplier 1*. It is not capable of delivering the same high volumes of semi-finished products and simultaneously it is not able to produce at the same low prices. Consequently, *Supplier 2* charges even a higher price per unit than *Supplier 1*.

The case of one retailer and three suppliers was then simulated. In this case the manufacturer company splits his requirements between the three suppliers (scenario 3). Scenario 4 consists of two suppliers with the call option contract. The call option allows the focal company to increase the number of ordered units later on during the year. The price of every single additionally produced unit of intermediate goods is more expensive than the goods produced under normal conditions. Additionally, this option requires the suppliers to reserve capacity. The manufacturer (focal company) has to pay a predefined amount of money for the reserving of capacity. The call option gives the focal company the flexibility to react to a possible disruption. Similar to scenario 3, scenario 5 consists of three suppliers. The difference between scenario 3 and scenario 5 lies in the other two suppliers. In scenario 5, *Supplier 2* and *Supplier 3* from scenario 3 are replaced by *Flexible Supplier 2* and *Flexible Supplier 3*, which have the call option supply contract. The last class of supply strategies (scenario 6 and 7) makes use of multiple suppliers with the put option supply contract. The units that have not been converted into finished products can be sold back to the supplier. The maximum amount of units that can be returned is negotiated between the buying and the selling firm before conclusion of the contract. In these scenarios, the focal company has to pay higher for the units exercised as put option.

Table 2: Simulation scenarios

	Single Sourcing	*Multiple Sourcing (2 suppliers)*	*Multiple Sourcing (3 supplier)*
Standard contract	*Scenario 1*	*Scenario 2*	*Scenario 3*
Flexible contract with call option		*Scenario 4*	*Scenario 6*
Flexible contract with put option		*Scenario 5*	*Scenario 7*

The simulation models were created with the simulation software Arena by Rockwell Automation Technologies Inc. Input data have been read into Arena from Microsoft Excel. The various supply chains from the seven scenarios are all simulated under four distinct circumstances according to the four risk profiles. In the first round of simulations, the main supplier, *Supplier 1*, has a reliance of 80 %. This means, every single day that is simulated there is a 20 % chance that *Supplier 1* will suffer from an outage. In the second round of simulations the reliance of *Supplier 1* is increased to 90 %, in the third it is increased to 95 % and in the fourth and last the reliance is even improved to 98 %. Hence, the whole spectrum from a very unreliable to a very reliable supplier and everything in between is covered. Demand is given by a normal distribution with a medium of $\mu = 300$ and a standard deviation of $\sigma = 60$.

Experimental Results

To compare the various supply strategies with each other, three performance measures have been chosen; fulfillment rate, profit and the duration of recovery under the disruption. While customer demand is fluctuating, the quantity-orientated β-service level measures the delivery performance between the manufacturer and the customer. It describes the ratio of total demand within a period that is delivered without delay form the stock on hand and is given as:

$$\beta = 1 - \frac{Expected\ backorders\ per\ period}{Expected\ demand\ per\ period}$$

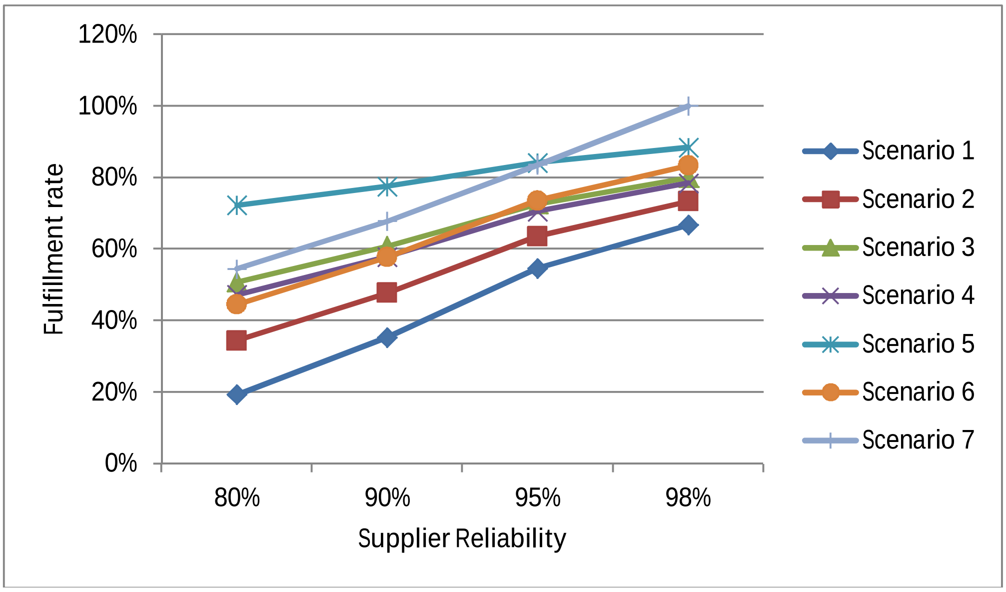

Figure 3 – Mean fulfillment rate under different scenario and different supplier reliability degree

The results of simulation experiment for the average service level under different scenario is given in Figure 3. Every single of the seven scenarios was simulated with the reliance of *Supplier 1* being changed from 80 % to 90 %, 95 % and finally 98 % according to the defined risk profiles. When *Supplier 1* shows a reliance of 80 %, scenario 5 has by far the best mean fulfillment rate followed by scenario 7 and scenario 3. For a reliance of 90 % the order stays the same. At 95 % the difference between scenarios 5 and 7 is almost negligible. Moreover, scenario 6 overtakes scenario 3. When *Supplier 1* shows a reliance of 98 %, scenario 7 shows a better performance. Its supply chain is capable of satisfying 100 % of the customer demand. The second best supply chain is the one from scenario 5. However it is only capable of achieving an 88.38 % mean fulfillment rate under these conditions. The mean fulfillment rates of scenario 1 are particularly low. When *Supplier 1* shows a reliance of 80 %, that means every day there is a 20 % chance that a disruption may happen, the supply chain of scenario 1 is only capable of satisfying 19.32 % of the customer demand.

In Figure 4, the evolution of the mean profits is depicted. The diagram shows that only scenario 5 is capable of achieving a profit for a reliance level of 80 %. For a reliance of 80 % and 90 % of *Supplier 1* the supply chain from scenario 5 generates the highest mean profits. For the other two levels of reliance the supply chain from scenario 7 produces the highest mean profits. When *Supplier 1* exhibits a reliance of 95 %, scenario 5 achieves higher mean revenue than scenario 7 but the mean costs of scenario 7 are much lower. Hence, scenario 5's mean profit is lower than scenario 7's. All the supply chains of the other scenarios make a loss. Furthermore, the difference between the highest and the lowest profit is much bigger at this level than at a reliance of 98 %.

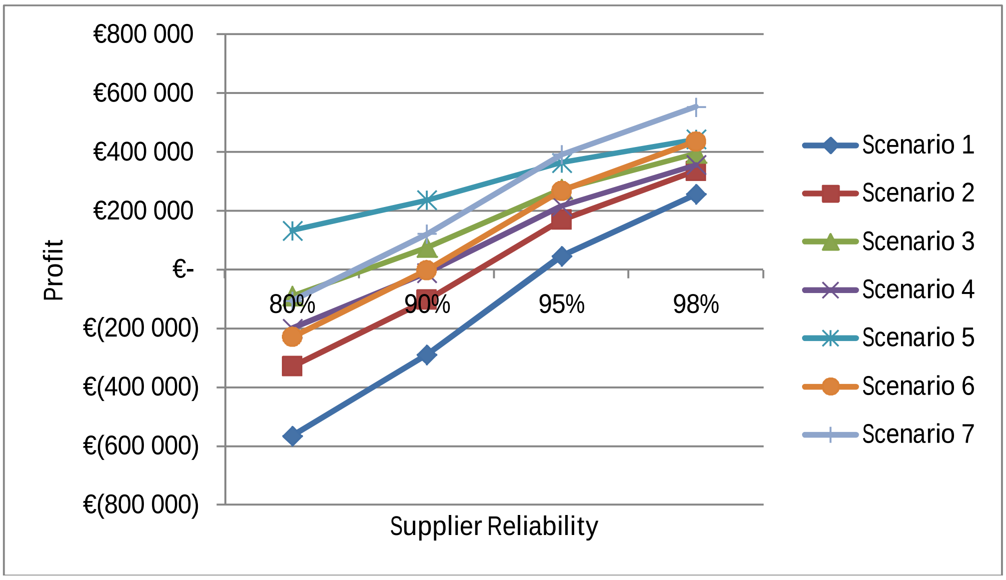

Figure 4 – Mean Profit

Like the simulations of a full year, the simulations of a single disruption are divided into days. The disruption of *Supplier 1* always takes place at the 100th simulated day and it lasts for 6 days. The results of fulfilment rate for each scenario are presented in Figure 5. Scenario 7 has the shortest recovery time, followed by scenario 5 and scenario 6. In addition, scenario 7 is among the three scenarios that are the least affected by the disruption together with scenario 5 and scenario 3. Consequently, scenario 5 and scenario 7 should cope best with multiple disruptions over the course of a year. Approving this assumption, scenario 5 displays the best results under an environment with a high disruption probability. In contrast to scenario 7 the supply chain in scenario 5 is capable of actively mitigating the effects of the disruption.

The duration of the different phases of supply chain resilience are listed in Table 3. For all seven scenarios the times of Avoidance are identical with an exception of scenario 1. Its Avoidance possesses the duration of three instead of two days. Regarding the Containment the scenarios exhibit differences. Scenario 1 has the shortest Containment because its fulfillment rate immediately drops to 0 %. Since scenarios 2, 3, 6, and 7 do not actively react to the disruption of *Supplier 1* their fulfillment rate drops for the complete duration of that disruption. Therefore, their Containment lasts six days. Scenarios 4 and 5 differ from all the others as they use supply contracts with call option. This option allows the supply chain to actively take measures to mitigate the effects of the outage. These measures in return shorten the Containment to three days and the improving of the fulfillment rate starts right away.

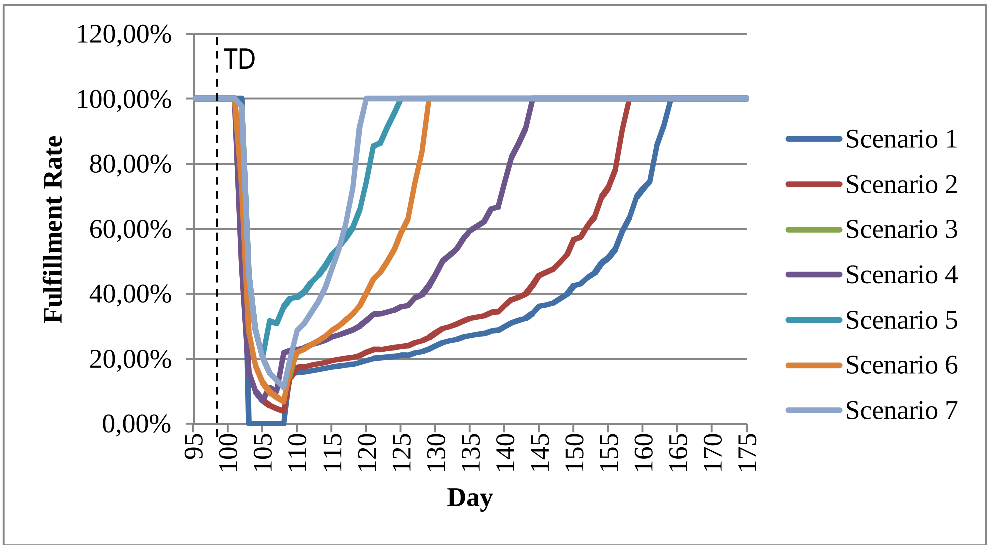

Figure 5 – Disruptions under different scenario

Table 3: Durations of the phases of resilience

	Avoidance	Containment	Stabilization	Return
Scenario 1	3	0	6	55
Scenario 2	2	6	1	49
Scenario 3	2	6	2	34
Scenario 4	2	3	3	36
Scenario 5	2	3	1	19
Scenario 6	2	6	2	19
Scenario 7	2	6	2	10

Table 4: Recovery time and severity of disruption

	Recovery Time	Severity of Disruption
Scenario 1	61	100.00%
Scenario 2	56	95.98%
Scenario 3	42	88.80%
Scenario 4	42	92.70%
Scenario 5	23	79.38%
Scenario 6	27	92.97%
Scenario 7	18	88.80%

Table 4 shows the recovery times and the severity of the disruption for each scenario. These two parameters determine the size of the resilience triangle and are therefore a good possibility to assess and compare the resilience of the seven scenarios. Scenario 7 exhibits the shortest recovery time, followed by scenario 5 and then scenario 6. The lowest severity of disruption is displayed by scenario 5, followed by scenario 7 and scenario 3. Consequently, scenario 5 and scenario 7 possess a similarly big resilience triangle. However, the shapes of the two triangles deviate from each other. At the other end of the spectrum, scenario 1 has the biggest and least favourable resilience triangle. Its recovery time is the longest and it possesses the worst possible severity of disruption with 100 %.

Conclusion

The increasing number and frequency of supply chain risks affect and alter the stability and normal operation of supply chains. A single supply chain partner might experience a disruption due to these risks, and as a result the complete supply chain is not able to fulfill its commitments any longer. These circumstances make it essential for a supply chain to be resilient to risks and to be capable of overcoming vulnerabilities, failures and disruptions. In a first attempt resilience can be achieved by reducing the probability of the occurrence of a disruption. However, not all outages can be prevented. Hence, it is essential for supply chains to mitigate the negative effects on the disrupted company and on the other supply chain members.

Upon deciding which flexibility option should be included into the contract it is important for companies to determine the general disruption probability within which their supply chain is operating. The simulation results of this research suggest to make use of a contract with a call option for high disruption probabilities and to make use of a contract with put option for lower disruption probabilities. Future research may be done on developing multi level supply chain that consists of all nodes. The effects of the several modes of supply, including the different supply contracts, on the other parts of the supply chain, especially the supplier(s) and the customer(s), have to be further investigated. In addition to these internal effects, external influences can also be incorporated into the models.

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SUPPLY CHAIN RISK MANAGEMENT AND DECISION SUPPORT TOOLS: A SYSTEMATIC LITERATURE REVIEW

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Abstract

Supply Chain Risk Management (SCRM) is in the agenda of both researchers and managers. In a context of increasing competitiveness and globalisation of relationships between organisations, SCRM is a global concern. This paper conducts a Systematic Literature Review (SLR) on the use of Decision Support (DS) tools within the risk management process. From the 107 papers reviewed, this study starts by clarifying different approaches regarding the definition of risk and the stages involved in the risk management process, and afterwards presents the SLR conducted in terms of methodology and its results and discussion. The main findings confirm SCRM and the identification use of suitable DS tools as a global topic, involving collaborations between researchers from different institutions, countries and continents. It was also possible to get an insight into the alignment between the DS tools proposed in the IEC/ISO 31010, Risk management – Risk assessment techniques and the results found in the SLR. Future research regarding the overview of DS tools not included in the IEC/ISO 31010 might provide interesting insights as to the stages of the risk management process where such tools are applied.

Keywords: Supply Chain Management, risk management process, Decision Support tools

1.Introduction

SCRM is a research area subject to growing attention in recent years (Dash Wu & Olson, 2009; Ghadge et al, 2012; Tang & Nurmaya Musa, 2011). The understanding of Supply Chains' (SC) underlying mechanisms, as well as related phenomena which might result in competitive advantage may dictate the difference between success and failure. There is an urgent need to know organisations' situation in real time, to create and use frameworks and tools that enable them to deal with these challenges (Fahimnia, et al., 2015).
The volatile business context, as well as the increasing pace of change in terms of products, technologies and other variables changes SC exposure to risk, and also the very nature of risk itself. Thus, typically stable and predictable SC, due to evolution, economic conjuncture or globalisation, might be exposed to increased disruption risk (Heckmann et al., 2014). Due to the magnitude of their impact on organisations, both in operational and financial terms, as well as their recovery ability, disruptions must be the object of particular caution and analysis (Jütner et al., 2003). Within this scope, tools that enable organisations to deal or reduce the risk of disruptions, from mitigation strategies to flexibility or alternative scenario planning are primordial in the recovery and reestablishment of SC (Tang & Nurmaya Musa, 2011).
SCRM literature points out the urgency of creating, developing and adapting Decision Support (DS) tools to manage risk events (Fahimnia et al., 2015). Existing reviews considering the use of DS tools in the context of SCRM present different perspectives, not focusing directly on the tools, but instead in topics such as the current state of SCRM and new, developing areas (Ghadge, et al., 2013; Tang, et al., 2011), price risks (Fischl, et al., 2014), enterprise risk management (with insights for Chinese companies) (Olson & Wu, 2010), quantitative models for managing risk (Fahimnia et al., 2015) or the clarification of aspects such as the definition, measurement and modelling of risk (Heckmann, et al., 2014). For both academic and managerial purposes, it would be useful to have the knowledge of which tools are currently being proposed to deal with the different stages in the risk management process. In that sense, the present review will

complement the existing ones with the perspective of which DS tools are applied to each stage in the risk management process.
This paper is organised in the following manner: it starts with a section addressing the topic of risk management in SC, presenting different approaches regarding frameworks and stages within the risk management process. Afterwards, the International Standard (ISO) framework for Risk management – Risk assessment techniques (IEC/ISO 31010, 2009) is outlined. In section 3, the SLR conducted in the field of SCRM is presented, providing details on the methodology followed. Within this section, the results of the SLR are presented, accompanied by its analysis and discussion. The DS tools identified will be discussed against the IEC/ISO 31010 framework. The scope for this study consisted of selecting the DS tools found in the SLR that are mentioned in the norm and its application within the risk management process stages. However, the identification of DS tools not included in the norm might provide interesting insights in terms of their use according to the IEC/ISO framework. The conclusions, research opportunities and limitations will be outlined in section 4.

2. Risk management in Supply Chains

The concept or risk has evolved across time and it remains vague and lacking finer definition. As a result of this evolution and change in nature, there are currently many risk classifications and approaches to define risk within the SCRM literature (Heckmann, et al., 2014; Huang, et al., 2009; Kull & Talluri, 2008). Definitions of risk might be presented as disruption, uncertainty, disaster, peril or hazard (Ghadge, et al., 2013). Two main dimensions derive from Jütner (2003) definition of risk as “the variation in the distribution of possible supply chain outcomes, their likelihoods, and their subjective values”: the idea of “risk impact”, pinpointing the consequences resulting from events in a given situation, affected by risk and the “likelihood of occurrence”, addressing the probability associated with unexpected events (internal or external) and how they might unsettle the organisation’s objectives and its performance (Colicchia, et al., 2011).
In a managerial sense, the meaning or risk could imply a variation in outcomes, performance failure or loss potential. Loss potential can be further decomposed in its magnitude and probability (T. J. Kull & Talluri, 2008). Heckmann et al. (2014) present a re-definition of supply chain risks as “the potential loss for a supply chain in terms of its target values of efficiency and effectiveness evoked by uncertain developments of supply chains characteristics whose changes were caused by the occurrence of triggering events”. The same authors find that risks may also be classified as endogenous, if they have origin within the risk situation or exogenous, arising from the outside (Heckmann et al., 2014). Olson (2010) further breaks down this categorisation, dividing external risks in three types: nature, political system and competitor and market; internal risks might arise from available capacity, internal operation or information system. Risk and uncertainty definition have also originated several approaches, with the first identified as having negative outcomes and the latter as the absence of information regarding a decision context (Cagliano, et al., 2012; Ritchie & Brindley, 2007).

2.1 Stages in the risk management process

As it was stated in the previous section, in what concerns the concept and definition of risk, several perspectives can also be found in terms of models and frameworks to manage risk in SC (Aqlan & Lam, 2015; Ghadge et al., 2013; Giannakis & Louis, 2011; Olson & Wu, 2010; Wang, et al., 2012; Wu, et al., 2006), as research and literature on SCRM have been growing rapidly over the last few years. Within these publications, several approaches on risk management can be found.
Ghadge (2013) proposes a conceptual framework for SCRM, according to a systems perspective, consisting of risk identification, risk assessment and risk mitigation (Figure. 1). In the first stage of the framework, risks are identified and classified (risk taxonomy), followed by risk trending, where boundaries for the operational risk variables are predicted. Within the risk assessment stage, risk modelling and sensitivity analysis are implemented resorting to quantitative modelling techniques. Risk mitigation draws information from risk trending, risk modelling and sensitivity analysis to define strategies. A different approach presents a risk analysis process, which includes risk assessment (aiming to estimate the probability of risk occurrence,

relating on quantitative and/or qualitative data), risk management and risk communication (Wang, et al., 2012). Aqlan (2015) proposes a framework combining qualitative and quantitative methods for Supply Chain Risk Assessment: risk identification, risk measurement and fuzzy risk assessment.

Figure. 1 – Framework for SCRM (source: Ghadge, 2013)

Focusing specifically on inbound supply chain risk analysis, found lacking in terms of existing research, Wu (2006) presents a procedure defined in four stages: risk classification, risk identification, risk calculation, and implementation/validation. In his multi-agent framework for SCRM, Giannakis (2011) considers that the disruption manager, in collaboration with SC partners, is responsible for carrying out the risk management process in four stages: risk identification, risk assessment, decision and implementation of risk management actions, and optimisation. Olson (2010) conducts a review of enterprise risk management in supply chain and presents several supply chain risk frameworks, targeting different application contexts, risks and approaches.
The frameworks and models identified in literature use different approaches and regard varied contexts. Regardless the fact they outline different numbers of stages or steps, they present several common features: (i) a concern with risk identification, quantification and taxonomy; (ii) a systems based approach, considering all processes involved and feedback and (iii) the need for communication and monitoring, reviewing and adjusting decisions and strategies.
Within the next section, the framework for the risk management process defined by the IEC/ISO 31010 is presented. As this document is an International Standard, it will be the approach adopted for further analysis regarding the risk management process within this study.

2.2 The risk management process according to the International Standard IEC/ISO 31010

The International Standard IEC/ISO 31010, presents a framework for the risk management process, highlighting the role of the risk assessment as the core set of activities that, nonetheless, should be integrated in the overall process (Figure 2). This document also provides direction in terms of the selection and application of techniques designed to perform risk assessment. According to the norm, the risk management process comprises the following elements:

- Communication and consultation, involving all stakeholders and integrating the process and other management disciplines within the organisation;
- Establishing the context, in terms of objectives, risk criteria and programme. The context provided should include the external and internal dimensions as well risk management context and risk criteria;
- Risk assessment, as the process of identifying, analysing and evaluating risk. Risk assessment is the core of the risk management process, “establishing an understanding of risks, their causes, consequences and their probabilities”;
- Risk treatment, the stage where one or more options intended to change the probability of occurrence of risk events, their effect, or both, are selected and agreed upon and implemented;

- Monitoring and review, ensuring the feedback regarding the validity of assumptions, achievement of results and the correct application of techniques and treatments.

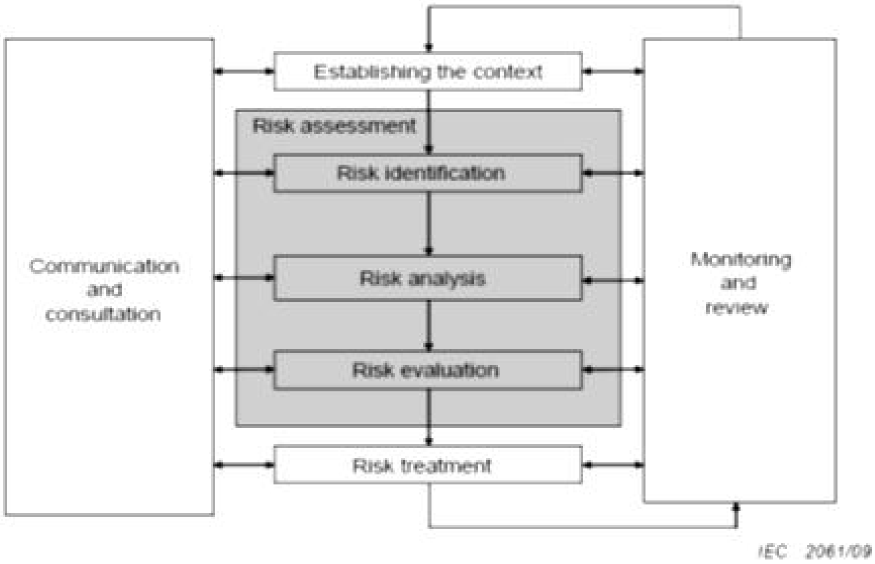

Figure. 2 – Contribution of the risk assessment to the risk management process (source: IEC/ISO 31010)

2.2.1 Risk assessment process

The risk assessment process is presented as the core of the risk management process within the IEC/ISO 31010. Risk assessment is intended to improve the stakeholders' understanding of risks that could interfere with the organisation's objectives and goals and whether the current practices are adequate and effective. By implementing the risk assessment process, organisations feed information to the decision-making processes. The context, techniques and methods applied determine the development of the risk assessment process activities. Risk assessment is defined by the norm as "the overall process of risk identification, risk analysis and risk evaluation".

Risk identification consists on finding, recognising and recording risks, locating the causes and sources of the risk, as well as "events, situations or circumstances that might have an impact on objectives and the nature of that impact".

Risk analysis seeks to develop an understanding of risk, by ascertaining the consequences and probabilities for identified risk events while being aware of "the presence and effectiveness of any existing controls". Risk analysis is carried out using qualitative, semi-quantitative or quantitative approaches, depending on the context, available data and organisational needs. The main steps involved are controls assessment, likelihood analysis and probability estimation, preliminary analysis, and uncertainties and sensitivities.

Risk evaluation carried out the comparison between "estimated levels of risk with risk criteria defined when the context was established, in order to determine the significance of the level and type of risk". Based on the knowledge and understanding of risk gained in the previous stages, stakeholders are enabled to make decisions regarding the need for treatment of risks identified, prioritisation in terms of treatment, the undertaking of activities and which action should be followed.

3. Systematic Literature Review (SLR)

A literature review is an important tool for formulating and clarifying research topics (Seuring, 2012), assisting in the process of setting the basis for building knowledge and providing a framework for theory emergence. Different research areas pose distinctive challenges in terms of the reviewing task. Management and organisational studies, being areas under development in terms of research, gather different research methods, tending to address more heterogeneous topics, with several disciplines coming forward as relevant. This research field encompasses many different subjects and topics and "academic communities easily detach from identification with the whole and can engage in their research unaware of work in associated areas" (Denyer, 2009).

Several studies agree on the fact that literature reviews provide support and guidance in synthesising information and expanding the knowledge base (Denyer, 2009; Seuring, 2012; Igarashi, et al., 2013). Furthermore, reviews might provide insight for both academics and managers, being useful in terms of new ideas, practices, or guidance. However, for literature reviews to be helpful for both academics and practitioners, they must be accessible and relevant, tackling real problems faced by managers. The key challenge remains to establish a link between science and practice in management research studies.

On recognising the importance of literature reviews, management and organisational studies are pointed out as lacking in terms of review procedures and criteria. Thus, Denyer (2009) proposes a systematic methodology for literature reviews that goes beyond the traditional approach, based on distinct and precise principles. Within a Systematic Literature Review (SLR) project, it is fundamental to inform the reader on the decisions made within the process of selecting relevant literature. According to Denyer (2009), a SLR is "a specific methodology that locates existing studies, selects and evaluates contributions, analyses and synthesizes data, and reports the evidence in such a way that allows reasonably clear conclusions to be reached about what is and is not known." Therefore, a SLR should be *transparent*, documenting each step taken and the inclusion/exclusion criteria in an open and explicit manner; *inclusive*, collecting the most relevant literature for the purpose of the study, gathering a wide range of data in order to promote a wider view on the topic; *explanatory*, including descriptive data and contributions from different studies to the research area; and *heuristic*, producing guides or protocols that might help to achieve solutions.

This study conducts a SLR on the topic of Supply Chain Risk Management, focusing on the application of Decision Support tools within the risk management process. The following section outlines the methodology followed in the search and selection procedures of the SLR.

3.1 Methodology

According to Denyer (2009), a SLR should have its focus well established by starting with a review question. The definition of the review question is benefited by the involvement and input of a "broad range of stakeholders", as they might help in clarifying the question and improve the whole review process, as well as the use of findings from the systematic review. The present SLR seeks to accomplish an understanding of DS tools currently used to manage risks within SC, identifying which DS tools are applied and the risk management stages they support.

SCRM is a rapidly expanding field in terms of research but, so far, the authors have no knowledge of studies linking the risk management process (and its stages, according to the IEC/ISO 31010) with the DS tools. We expect the findings of this review to enable the definition of a risk management framework integrating the utilisation of DS tools within the different stages of the risk management process.

The following step consisted of searching the literature to carry out the systematic review. "Systematic reviews aim to locate, select, and appraise as much as possible of the research relevant to the particular review question(s) (Denyer, 2009). In order to search for the relevant papers, an extensive search was carried out using the keywords "supply chain" AND "risk management" AND "decision" OR "supply chain" AND "risk management" AND "tools". The databases selected were Scopus, Science Direct and Web of Science. These databases were selected looking for best coverage of existing publications in the area. The search conducted produced 1457 results. The selection and evaluation process followed is documented in Figure 3.

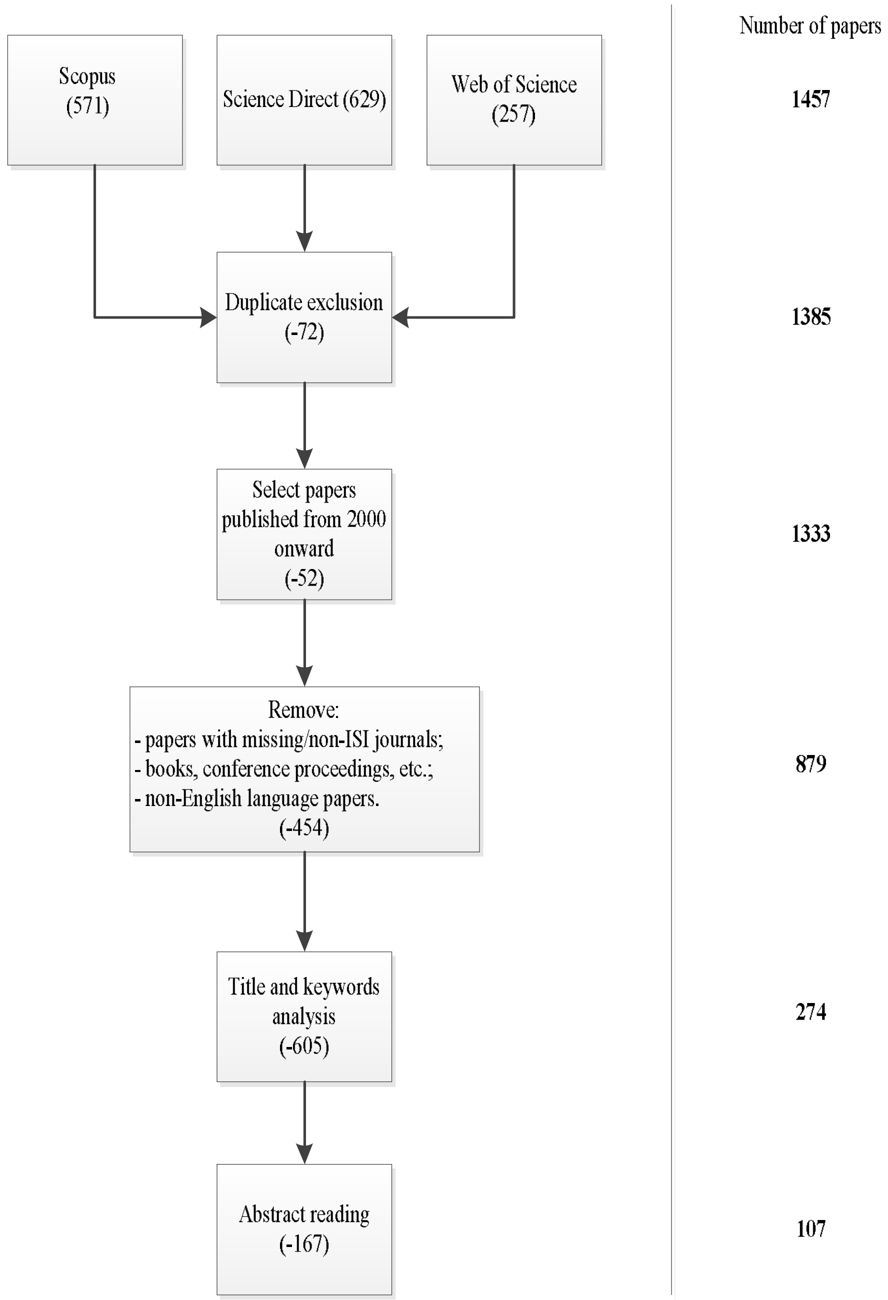

Fig. 3 – Literature search and selection process

The first step consisted on eliminating duplicates. A total of 72 papers were identified as such. Afterwards, papers published until 2000 were abandoned (52) and papers published until 2015[5] were considered for further analysis. The following procedure removed papers in languages other than English, as well as other types of studies, such as book chapters or conference proceedings. Also at this stage, papers not published in ISI journals were also removed. In total, 879 papers were excluded by the application of these criteria. From the reading and analysis of title and keywords, a set of 274 papers emerged. The final step of the process

[5] Papers published until the 31st of May, 2015.

consisted of reading the abstracts, looking for SD tools used within the stages of the risk management process. A total of 107 papers were considered relevant according to the scope defined.

3.2 Results and discussion

From the final set of 107 papers, it is clear that there is a growing number of publications addressing the use of DS tools to manage risk within the SC (Figure 4) from the years 2001 to 2015 (papers published until the end of May).

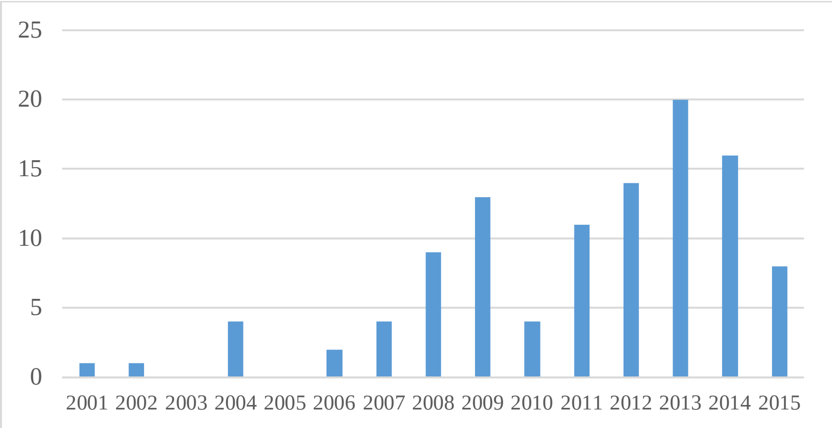

Figure 4 – Number of papers published per year

To provide further evidence that this is a global topic, Figure. 5 shows that research is being carried out mainly in North American (36%) and European (40%) countries, but also in Asian countries (such as China and Taiwan) and Australia. Additionally, 28% of the papers reviewed resulted from the collaboration of authors from different countries and 16% of them joined researchers from different continents. To reinforce the strong cooperation in this research area, 96% of the papers were written by more than one author and 63% gathered people from different institutions.

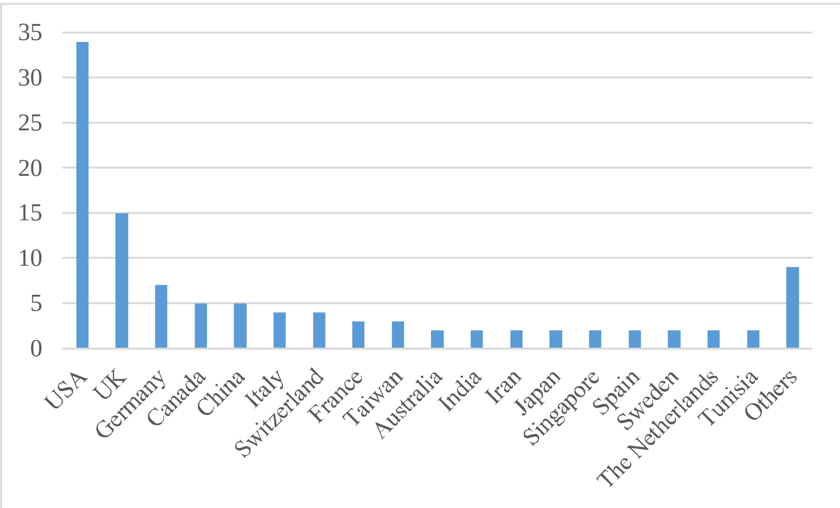

Figure 5 – First author's country

Over 75% of the final set of papers was published on the journals listed on Table 1. Publications of reference such as the International Journal for Production Economics (15%), the International Journal of Production Research (12%), Supply Chain Management: An International Journal (7%), the International Journal of

Physical Distribution & Logistics Management (5%) and the Journal of Risk Research (5%) accounted for more than a half of the papers analysed during the review process.

Table 1 – Number of papers published per journal

Journal name	Number of papers
International Journal of Production Economics	16
International Journal of Production Research	13
Supply Chain Management: An International Journal	7
International Journal of Physical Distribution & Logistics Management	5
Journal of Risk Research	5
European Journal of Operational Research	4
Journal of Business Logistics	4
Decision Support Systems	3
Expert Systems with Applications	3
Industrial Management & Data Systems	3
Journal of Operations Management	3
Journal of Purchasing and Supply Management	3
Omega	3
Production Planning & Control	3
AIChE Journal	2
Computers & Industrial Engineering	2
Computers in Industry	2
Others	26

From the final set of papers, dividing them according to the type of research conducted, 45% are case studies, 35% conceptual papers, 15% empirical studies and the remaining 6% are literature reviews. The main emphasis is on empirical research (60% of the papers analysed).

Regarding the classification in terms of industrial sector, from the 107 papers analysed, 41 did not contain any such reference. This number accounts for about 38% of the final sample. Papers relating with no industry sector are mainly conceptual papers (30), but there are also empirical papers (6) and literature reviews (6).

The growing number of publications has originated 6 literature reviews. Ghadge et al. (2012) and Fischl et al. (2014) conduct SLR: the first, looking for present and future scope within the SCRM research area and the latter focusing on price risks. Olson (2010) performed a literature review on the topic of enterprise risk management, reviewing the Chinese supply risk case. Fahimnia et al. (2015) carried out a bibliometric and network analysis to generate insights into the quantitative models for managing SC risks. Heckmann et al. (2014) conducted a critical review on SC risk, aiming to clarify aspects such as the definition, measurement and modelling of risk. Last, Tang (2011) presents a literature survey and citation/co-citation analysis to investigate research developments in SCRM, as well as gaps and areas receiving less attention.

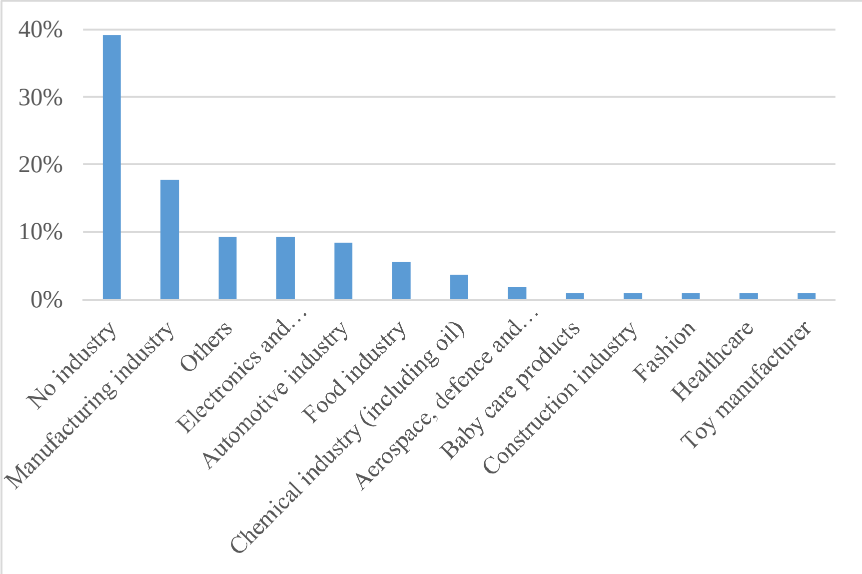

Figure 6 – Papers per industry sector

The remaining 65 papers (most of them case studies) refer to varied industrial sectors, as shown in Figure 6. There is a predominance of general manufacturing, electronics and automotive industries, but new inputs are arising from food industry, aerospace, defence and aeronautics, fashion or healthcare. These findings confirm that, besides being a global topic, SCRM and the use of DS tools are topics disseminated across a multitude of industrial activities.

The main focus of this SLR is to seek further awareness and understanding of which DS tools are currently used by organisations to manage risks within their SC. From the papers analysed, we gathered the following results concerning the use of DS tools: first finding (i) is that 10 papers do not directly apply DS tools (4 of these are conceptual papers, 2 case studies, 1 empirical paper and 3 literature reviews), but indirectly mention their use.

Within the conceptual papers, different perspectives and tools are presented, regarding risk management as a "tool for greater rewards, not just control against loss" (D. D. Wu & Olson, 2009) and studying the different sources of risk and measures for its reduction, with the recognition that there is no generalised supply chain performance measurement system and that most supply chain analysis models are too simple to represent complex production situations (Xiaohui, et al., 2006). Zhang et al. (2011) provide a perspective on supply chain quality and coordination, as well as technology application and issues regarding SCRM and reliability control. According to this study, there is still scope for "continuous supply chain improvement, strategic planning, tactical employment and operational tools" that address quality issues and produce satisfactory supply chain quality for stakeholders (Zhang et al., 2011).

Supply chain logistic risks are presented by Cavinato (2004), who argues that supply chains are formed by five internal/network constructs: physical, financial, informational, relational and innovational. The case studies mentioned report Ericsson's proactive SCM approach, following problems faced with suppliers (Norrman & Jansson, 2004) and the implications of an earthquake for Toyota and the consequent disruptions in the company's SC (Matsuo, 2014). The empirical paper analyses the severity of supply chain disruptions based on "multiple-method, multiple-source empirical research (Craighead et al., 2007). The authors relate the "severity of supply chain disruptions (i) to the three supply chain design characteristics of density, complexity, and node criticality and (ii) to the two supply chain mitigation capabilities of recovery and warning all supply chains are inherently risky because all supply chains will experience, sooner or later, one or more unanticipated events that would disrupt normal flow of goods and materials". The 3 literature reviews found applying no DS tools focus on different topics regarding SCRM. Fischl et al. (2014) seek to gain knowledge relevant to the management of price risks in manufacturing companies, considering the operations management perspective. By conducting a SLR, the authors investigate approaches to price risk

management by considering risk mitigation strategies and risk management frameworks and their application/adaptation to price risk management. Their main findings state that scarce attention is paid to price risks and their management in manufacturing companies and a recommendation is left to engage in further empirical investigation in order to support the process of decision-making in different contexts and situations as, until now, little research has considered the inclusion of contextual factors. The literature review conducted by Heckmann (2014) gathers existing approaches focused on quantitative SCRM and associated concepts. Starting with the evolution of the risk concept, different perspectives on supply chain risk definitions and its core characteristics are presented, providing a comparison of commonly used risk measures. Supply chain optimisation is the focus of the mathematical approaches presented, which model supply chain design and planning, referring to supply chain risk. The authors conclude that "the real challenge in the field of supply chain risk management is still the quantification and modelling of supply chain risk", as there is a gap in terms of unequivocal and suitable measures for supply chain risk that grasp the understanding of the features of modern supply chains. The last review is by Olson (2010) and focuses on the identification and clarification of types of risks, cases and models, presenting specific aspects of risk in supply chains involving China, which has become a major player in terms of international trade.
The second finding (ii) is that, in 34 papers the authors use one DS tool and the third discovery (iii) is that, in the remaining 61 papers, multiple DS tool are put to practice. This last matter might also bring forward evidence that organisations can take advantage from the articulation of multiple DS tools.

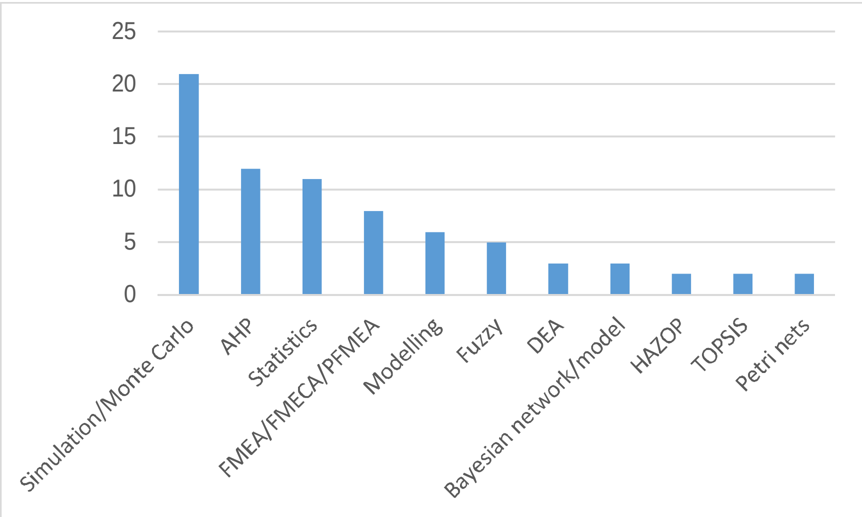

Figure 7– Most commonly used DS tools in the SLR

In terms of the DS tools applied, Simulation/Monte Carlo is used in 21 papers, followed by AHP (12), Statistics (11), and FMEA/FMECA/PFMEA (8), as shown in Fig. 7. From the most commonly applied DS tools, only HAZOP produces no quantitative output. Also, from this range of DS tools, AHP, modelling, fuzzy techniques, DEA, Petri nets and TOPSIS are not referenced in the norm IEC/ISO 31010. From the tools proposed by the norm, we have made a distinction between Bayesian statistics/nets and other statistical techniques, such as regression, ANOVA and factor analysis, among others found in the review. The first is included in the set of tools proposed in the norm, but the latest are not. In Table 2, a summary of the DS tools identified in the literature review is provided, crossing the tools with their suitability within the risk assessment process, according to the IEC/ISO 31010 framework (SA: strongly applicable; NA: not applicable; A: applicable).

Table 2 – Applicability of tools used for risk assessment (adapted: IEC/ISO 31010)

<table>
<tr><th rowspan="3">Tools</th><th colspan="5">Risk assessment process</th></tr>
<tr><th rowspan="2">Risk identification</th><th colspan="3">Risk analysis</th><th rowspan="2">Risk evaluation</th></tr>
<tr><th>Consequence</th><th>Probability</th><th>Level</th></tr>
</table>

				of risk	
Simulation/Monte Carlo	NA	NA	NA	NA	SA
FMEA/FMECA/PFMEA	SA	SA	SA	SA	SA
Bayesian network/model	NA	SA	NA	NA	SA
HAZOP	SA	SA	A	A	A

It is relevant to state that only 55% of the most commonly used DS tools found in the present literature review can be found in the methods available to perform risk assessment, as prescribed by the aforementioned norm. That leaves a total of 45% of studies that apply DS tools not included in the norm. A question might be raised inquiring on the usefulness and application scope for the tools proposed by IEC/ISO 31010. A different perspective might lead to investigate whether the DS tools proposed by the norm might be better suited for managerial application and less so in academic context.
From the DS tools analysed, simulation/Monte Carlo is applied in 20 different studies. It is one of the tools proposed by IEC/ISO 31010 and its utilisation is documented in Table 3.

Table 3 – Studies applying simulation/Monte Carlo techniques

Author(s), year	Application context	Other tools	Goal	Industry
Elleuch, et al., 2013	SCRM framework comprising of different techniques and specialized procedures is proposed that can assist supply chain decision makers to risk identification, assessment and management	FMECA, DOE, AHP	Assess risks mitigation action scenario	Healthcare
Hong & Lee, 2013	Decision support system to model risks for procurement processes and to design a robust purchasing plan, including supplier selection and order allocation.	Pairwise comparisons	Supply risk assessment	Electronics
Schmitt & Singh, 2012	Analysis of inventory placement and back-up methodologies in a multi-echelon network and their effect on reducing supply chain risk	-	Assess the impact of disruptions	Consumer packaged goods
Colicchia et al., 2011	Evaluation of strategies for managing global inbound supply risk	-	Assessment of SCRM strategies impact on firm	Home appliances; braking systems for vehicles
Ghadge et al., 2013	Development of a holistic, systematic and quantitative risk assessment process for measuring the overall risk behaviour; industrial case study	Statistical modelling	Risk modelling	Aerospace and defence
Lee, et al., 2012	Generic framework to assess and simulate outsourcing risks in the supply chain	SCR-FMEA	Assessment of outsourcing risks in supply chain performance	Manufacturer of refrigeration compressors
Canbolat, et al., 2008	Emerging market sourcing risk assessment and management model for sourcing components and sub-systems to emerging	PFMEA	Quantification of risk factors	Automotive manufacturer

	markets; industrial case study			
Talluri, et al., 2013	Evaluation and proposition of efficient supply chain risk mitigation strategies in the presence of a variety of risk categories, risk sources, and supply chain configurations	DEA, non-parametric statistics	Analyse and rank alternative mitigation strategies	-
Galasso & Thierry, 2009	Approach based on simulation and decision theory enabling a risk evaluation of the demand management processes according to different scenarios	-	Evaluation of different cooperative processes in terms of risk	Aeronautical industry
Mizgier, et al., 2015	Model for the quantification of business disruption risk in a global supply chain network	-	Calculate the loss distribution from disruptions	-
Manuj & Mentzer, 2008	Simulation model development process for the design, implementation, and evaluation of logistics and supply chain simulation models	-	Understand the impact of risks on global supply chains	-
Wei, et al., 2009	Assessment of the impacts of disruptive events on supply chain networks under an unsafe environment	IIM, OWA	Validate the accuracy of the model developed for risk management and mitigation strategies	White alcohol production
Bandaly, et al., 2013	Integrated approach to SCRM using operational methods and financial instruments	Stochastic optimisation model, simulation-based optimisation	Performance assessment in terms of risk aversion, demand variability and price volatility	Brewery
Cigolini & Rossi, 2010	Analysis and assessment of the operational risk at the drilling, primary transport and refining stage of the oil supply chain	HAZOP, ETA	Risk assessment (outlining the magnitude of damage)	Oil industry
You, et al., 2009	Risk management for mid-term planning of a global multi-product chemical supply chain under demand and freight rate uncertainty	stochastic programming, multicut L-shaped method	Assessment of the potential improvement of using stochastic programming in the supply chain planning process	Major commodity chemical producer
Olson & Wu, 2011	A priori evaluation of potential partners, not only in terms of expected cost, but also in terms of other risks; outsourcing to China	DEA	Generation of average overall costs (risk-adjusted costs, based on which preferred outsourcing sites	-

			could be determined)	
Klibi & Martel, 2012	Risk modelling approach to facilitate the evaluation and the design of Supply Chain Networks (SCNs) operating under uncertainty; two realistic case studies	Hazard modelling	Generation of risk scenarios in order to derive performance evaluation weights for risk neutral or risk adverse decision-makers	North-American two-echelon distribution network, worldwide humanitarian peacekeeping and peace enforcement network
Manuj, et al., 2014	Effectiveness of different supply chain risk management approaches by examining how performance varies when these approaches are applied under different risk conditions	grounded theory, SDT, ANOVA	Generation of scenarios for strategic approaches and supply- and demand-side risk conditions	Manufacturing firms
Wu & Olson, 2008	Paper considers three types of risk evaluation models within supply chains: chance constrained programming (CCP), data envelopment analysis (DEA), and multi-objective programming (MOP) models	CCP, DEA, MOP	Support in selecting preferred suppliers taking risk factors into consideration	-
Kull & Closs, 2008	Supply risk issue within the context of a second-tier supply failure	modelling	Evaluating exposure to supply risk	-
Guertler & Spinler, 2015	Investigation of internal interrelationships and insights into the operational dynamics of single supply chain enterprises	scenario analysis	Assessment of the criticality of operational risks	Automotive industry

According to the IEC/ISO 31010, simulation/Monte Carlo are DS tools strongly applicable to risk evaluation, a stage in the risk assessment process that "involves comparing estimated levels of risk with risk criteria defined when the context was established, in order to determine the significance of the level and type of risk". This knowledge will allow informed decision making. Within the 21 papers analysed in Table 3, the goals presented for the application of simulation/Monte Carlo tools are aligned with the applicability specified by the norm, thus showing alignment between the norm and the use of DS tools in research and managerial contexts (case studies).

Failure modes and effects analysis (FMEA) is, from the tools presented in IEC/ISO 31010, the second in terms of utilisation among the papers reviewed. This tool presents variants such as Failure modes and effects and criticality analysis (FMECA) or Process failure modes and effects analysis (PFMEA). The referred tools were all considered under the same scope in terms of applicability, in accordance with the norm. Table 4 presents the reviewed papers where this tool (or any of its variants) was applied. From the norm, it is clear that these are transversal tools, strongly applicable to all stages within the risk management process. By looking up Table 4 we find that risk identification, risk assessment, categorisation of risks and its impact are carried out by applying this tool. These goals are well aligned with application directions by the norm.

Table 4 – Studies applying FMEA/FMECA/PFMEA techniques

Author(s),	Application context	Tools	Goal	Industry

year				
Elleuch, et al., 2013	SCRM framework comprising of different techniques and specialized procedures is proposed that can assist supply chain decision makers to risk identification, assessment and management	FMECA, DES, DOE, AHP	Identify risk	Healthcare
Chen & Wu, 2013	Modified failure mode and effects analysis (MFMEA) method to select new suppliers from the supply chain risk's perspective	AHP, Modified FMEA	Select the supplier with the lowest risk in order to reduce the holistic supply chain risk	Integrated circuit assembly
Bradley, 2014	Improved risk measurement and prioritization method to account for the characteristics of rare risks	FMEA	Measurement and prioritisation of risks	-
Lee et al., 2012	Generic framework to assess and simulate outsourcing risks in the supply chain	SCR-FMEA, Monte Carlo	Risk identification, analysis and mitigation actions	Manufacturer of refrigeration compressors
Canbolat et al., 2008	Emerging market sourcing risk assessment and management model for sourcing components and sub-systems to emerging markets; industrial case study	PFMEA, simulation	Characterise the impact of risk	Automotive manufacturer
Kumar & Havey, 2013	Decision support risk assessment and mitigation framework for disaster relief supply chain	FMECA	Assessment of likelihood of potential failure points	-
Lavastre, & Spalanzani, 2014	Framework for supply chain risk management is proposed and applied using the data collected from 164 French companies, in the manufacturing sector.	FMECA, statistics	Rank the risks from most to least critical	French manufacturing companies
Tuncel & Alpan, 2010	Study aims to show how a timed Petri nets framework can be used to model and analyse a supply chain network which is subject to various risks	FMECA, Petri nets, performance evaluation	Risk identification and assessment	Supplementary parts for electric, automotive, and home appliances

Table 5 shows the results for the use of Bayesian techniques. According to the norm IEC/ISO 31010, these are strongly applicable in risk analysis (in terms of regarding consequences, whether it is through description of possible outcomes, quantitative modelling or vulnerability analysis) and risk evaluation. Two of the papers presented in Table 5 use Bayesian techniques to analyse risk ((Li & Chandra, 2007; Shin, et al., 2012) while the third one aims at evaluating risk by measuring it within the supply chain.

Table 5 – Studies applying Bayesian techniques

Author(s), year	Application context	Tools	Goal	Industry
Li & Chandra, 2007	Investigate and develop a generic knowledge integration framework that can handle the challenges posed in complex network management	Bayesian model	Seek analytical solutions	Information technology
Garvey, et al., 2015	Development of a model of risk propagation in a supply network	Bayesian network	Measure the risks within a supply chain	-
Shin,et al., 2012	Framework to develop alternative backorder replenishment plan to minimise the total replenishment cost and expected risk cost	Bayesian Belief Network, Key Risk Indicator	Model the relationship between risks and risk propagation	-

The last of the DS tools identified in the papers reviewed and referred in the norm is Hazard and operability studies (HAZOP). This tool was applied in two papers, both in the oil industry sector. HAZOP, according to IEC/ISO 31010 is a strongly applicable tool for risk identification and risk analysis and this recommendation is in accordance with the results found in the literature revision.

Table 6 – Studies applying HAZOP

Author(s), year	Application context	Tools	Goal	Industry
Cigolini & Rossi, 2010	Analysis and assessment of the operational risk at the drilling, primary transport and refining stage of the oil supply chain	HAZOP, ETA, simulation	Risk analysis and risk assessment	Oil industry
Adhitya, et al., 2009	Structured methodology for risk identification using methods and concepts from chemical process risk management adapted to supply chains	PFD, HAZOP	Risk identification	Refinery

Within the DS tools referred in IEC/ISO 31010, several papers reviewed resort to more than one of those. Simulation and FMEA are used in three cases. Elleuch, et al. (2013) complement the identification of risks through FMEA with the assessment of risks mitigation scenarios, using simulation, whereas Lee et al. (2012) applies supply chain risk FMEA to identify, analyse and mitigate risks and, through simulation, conducts the assessment of outsourcing risks in supply chain performance. Last, Canbolat et al. (2008) applies Process FMEA to characterise the impact of risk and simulation to quantify risk factors. Simulation is also used together with other tool, HAZOP, by Cigolini (2010). This study applies HAZOP to analyse and assess risk and simulation to outline the magnitude of damage caused by risk.

For a more thorough analysis of DS tools used in the context of SCRM, the overview of the tools not included in the IEC/ISO 31010 might provide interesting insights as to the stages of the risk management process where such tools are applied, but that scrutiny is beyond the scope of this study.

4. Conclusions (Research opportunities & Limitations)

SCRM is a research area gathering interest from researchers and managers. The use of DS tools within the risk management process is a topic receiving growing interest in terms of research and publications. For both academic and managerial purposes, it is highly relevant to know which tools are currently applied to deal with the different stages in the risk management process.

This paper conducted a SLR where existing literature concerning the use of DS tools within the SCRM process was gathered. The literature was then assessed according to the criteria presented and a final set of 107 papers were considered relevant. From those papers, results documented a growth in terms of publications, as well as multiple collaborations, involving researchers from different institutions, countries and continents is common research projects. In what concerns with industry sectors, manufacturing, electronics and automotive industries are predominant, but in the most recent years, research has also focused in food industry, aerospace, defence and aeronautics, fashion or healthcare. These results confirm that, besides being a global topic, SCRM and the use of DS tools are topics disseminated across a wide range of industrial activities.

The SLR conducted aimed at seeking an understanding regarding DS tools currently used within literature to manage risks within supply chains, identifying which DS tools are applied and the risk management stages they support in terms of decision making. From the overall set of DS tools found in literature, only four were referenced in the norm IEC/ISO 31010: simulation/Monte Carlo, FMEA/FMECA/PFMEA, Bayesian techniques and HAZOP. The application of these tools was scrutinised in terms of context, goal, industry sector and its use (or not) in combination with other tools. The application of the DS tools identified was found in accordance with the applicability to each step of the risk assessment process. Four situations were identified that used a combination of two tools, achieving results in more stages of the risk assessment process.

A limitation of this study resides on the fact that, by taking the IEC/ISO 31010 norm as the framework for the analysis, only the tools presented there were reviewed in terms of its application. Future research on the topic might find interesting insights in the application of the other DS tools identified, the stages they are applied to and the results achieved. This development would allow the SLR conducted to realise its potential in terms of DS tools used to support the risk management process within supply chains.

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DISASTER RECONSTRUCTION HOUSING SUPPLY NETWORK IN THE AFTERMATH OF VALPARAÍSO FIRE 2014

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Abstract

In the aftermath of a disaster, housing is both the physical artefact provided by a disaster reconstruction housing supply network, as well as an integral part of the affected community and its resilience. The paper studies the reconstruction in the aftermath of the Valparaíso fire of 2014 in order to shed light on how a disaster reconstruction housing supply network contributes to the resilience of a disaster-affected community. It describes the housing reconstruction supply network for both the formal and informal settlements of Valparaíso and highlights how vulnerability and resilience do not lie at the opposite ends of the scale.

Keywords: informality, disaster reconstruction, humanitarian logistics, supply chain management

Introduction

When the storm winds have died out, the flood waters retreated, the gun-fire seized and the earth lies still, the disaster is not over. It's just beginning to unravel. Humanitarian disasters unfold amidst the fallen-down buildings, the broken roads, the lost lives and livelihoods. While hazards such as earthquakes, hurricanes or wars shake entire cities, regions and nations, the disaster falls disproportionately on those who were most socio-economically and environmentally vulnerable prior to the event. (Ibarrarán et al., 2009; Masozera et al., 2006) Even if everyone can see the spark, not everyone is burned equally by the fire.

When a hazards hits, governments mobilize their resources to protect their citizens and humanitarian actors start providing aid following the humanitarian principles of humanity, neutrality, impartiality and independence. (OCHA, 2010) Humanitarian logistics and supply chain management, a field that studies the provision of continuous aid and the organization of disaster relief, categorizes disaster relief effort into three phases: preparation, immediate response and reconstruction. (Kovács & Spens, 2007) Within this field, relatively little research focuses on reconstruction. (Kunz & Reiner, 2012)

Meanwhile, as climate-change induced disasters and conflicts are on the rise and continue to affect innumerable regions and populations, building future disaster preparedness into the disaster reconstruction is considered crucial. The idea of weaving disaster preparedness into disaster reconstruction is referred to as "Build Back Better" and it is stated as one of the four priorities in the Sendai Framework for Disaster Risk Reduction adopted in March 2015 for the next fifteen years to come. (UNISDR, 2015) The discussion on effective disaster resilience and relief is also active on the side of the humanitarian system. According to ALNAP's 2015 report, the State of the Humanitarian system, in terms of financial and human resources the humanitarian system is larger than ever, but the focus is on fewer disasters that affect a larger number of people. The report analyses that while the humanitarian system has improved, "the improvements are largely focused on the process of aid delivery rather than on substance and outcomes". (ALNAP, 2015 p. 14) Furthermore, the report recognizes that the principal need for many affected by the current emergencies is protection, "the area humanitarian action is least able to affect". (ALNAP, 2015, p.11) The reconstruction phase is the vital link between the alleviation of current suffering and the future everyday life of the disaster affected communities.

However, the ideologies and technologies for building back better often come from the outside of the socio-economically and environmentally vulnerable communities. While through the physical disaster reconstruction of houses and neighborhood infrastructures it is possible to reduce the impacts of the future hazards on those most vulnerable, rebuilding physical infrastructure is just one step on the way to a community's recovery from a disaster. (e.g. Cutter et al., 2008) If reconstruction is built for the disaster-affected community without understanding the role of their infrastructure in their lives and for their livelihoods, the solutions provided may not lead to long-term psychological and physical healing of the community. (Barrios, 2014) Sturdy walls themselves don't make a resilient home.

Disaster relief and management is studied under a variety of labels, laying emphasis on different actors from governments to communities, and there are a variety of buzzwords that circulate the topic: from adaptation to vulnerability and on to resilience of late. (e.g. Smit & Wandel, 2006) Resilience as a concept comes from the side of natural sciences, where it refers to a matter's ability to bounce back to its pre-shock state. (Holling, 1973) Some authors on disaster resilience see resilience as an opposite of vulnerability (Wilson, 2012), while others perceive vulnerability and resilience to be two overlapping concepts (Turner II, 2010). Community resilience, within social sciences, has come to encompass the discussion of how disaster affected communities can face, recover from and prepare for disasters. Much of community resilience literature focuses on the psychological aspects of disaster recovery, the physical element, the place and its infrastructure, is also involved. (Bilau et al., 2015) Meanwhile, some authors set out to discuss resilience, but end up focusing on the robustness of infrastructures, highlighting how intertwined the psychological and physical worlds are in the sense-making of disasters. (e.g. Joerin et al., 2012)

Communities and their resilience are intertwined with place and infrastructure in differing ways. Urbanization and related phenomena - such as the increasingly ubiquitous internet - challenge the way communities, infrastructures and their resilience are viewed. 54% of the global population resided in urban areas in 2014 and that figure is expected to reach 66% by 2050. (United Nations, 2014b) As the urban population is growing, so are the informal settlements surrounding the cities. In low- and middle-income nations between one-third and one-half of the population live in informal settlements – also in the economically successful cities. (IFRC, 2010) According to UN, the "rapid and unplanned urban growth threatens sustainable development when the necessary infrastructure is not developed or when policies are not implemented to protect the environment and ensure that the benefits of city life are equitably shared". (United Nations, 2014b, p.1).While the notion of what "sustainable development" or "development" is and whether it is worth pursuing can be debated, (e.g. Gudynas, 2011) understanding and supporting disaster resilience in the informal settlements needs to be addressed.

This paper looks at housing reconstruction in the aftermath of disasters from two angles: from the perspective of disaster relief and from that of community resilience. This way the artefact, the house, is both the product delivered by a disaster reconstruction housing supply network, as well as part of the community, its infrastructure and its resilience. To truly address resilience and vulnerability, the paper takes into account the specificities of both formal and informal settlements. This is important because if the processes, frameworks and tools addressing disaster reconstruction tend to start with an assumption on a formal and legal context, the minds and hands of the people executing the actions from the organizations' side may be bound in finding working solutions for the informal settlements.

The research questions answered by the paper are the following:

- How does a disaster reconstruction housing supply network contribute to the resilience of a disaster-affected community?
- How does the community resilience depend on whether the settlement is formal or informal?

The following chapters continue with a literature review on disaster reconstruction supply chains networks and vulnerability, resilience and informality and formality of settlements. After this the methodology of the paper is introduced in the fourth chapter, along with background to the case of the Valparaíso fire to be studied. The fifth chapter discusses the (in)formality of the settlements in Valparaíso in the status quo and the sixth chapter discusses the disaster reconstruction housing supply networks in the aftermath of the Valparaíso fire, with respect to the (in)formality of the settlements. The paper concludes with a discussion and conclusions and illustrates how the housing reconstruction supply network differed between the formal and the informal settlements in the aftermath of the Valparaíso fire in 2014 and how the housing construction supplier set-up had implications on the resilience of the communities affected by the disaster.

Disaster reconstruction supply networks

Supply chain management and logistics have entangled roots. (Cooper et al., 1997) Logistics is a more pragmatic concept for getting the right things to the right place, with "roots firmly planted in rubber-meets-road practicality" and boots in the military operations. (Fawcett & Waller, 2011, pg.1; Rutner & Langley, 2000; Cowen, 2014) While also logistics started reaching towards more strategic dimensions, the concept of supply chain management came along, swallowed logistics and came to address the more strategic aspects of organizations delivering value. Mentzer et al. (2001), for example, define supply chain management as "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole". This definition underlines how the purpose of the supply chain is to improve the organizational performance of the entities participating in it.

Similarly as logistics also supply chain management in its footsteps is often considered as the necessary, yet undesirable generator of costs within a company, much of the performance improvements are concerned with reducing costs. Efficiency and effectiveness are concepts to describe and measure performance. Mentzer and Konrad (1991) define effectiveness as "the extent to which goals are accomplished" and efficiency as "the measure of how well the resources expended are utilized". The optimally performing supply chain would then accomplish pre-set goals with little resources.

However, what are the goals to be met? Conventional business people and scholars would argue that the primary purpose of a company is to make profit and generate revenue, and that these financial indicators reveal the success of a company and justify its existence. Along the lines of this though, also the success of the supply chain can be broken down to financial indicators for efficiency and effectiveness. However, the tide on the commercial side is changing towards prioritizing the value added to the customer. Demand(-supply) chain management is a concept that has turned the idea of a supply chain around: the supply side is equally important as the demand side, but the network of organizations is not pushing things to the customer out there, but providing to their demand. (Hilletoft, 2009; 2011) The demand-supply chain is still there to serve, efficiently, effectively and obediently (yet with a little more autonomy and self-respect), but the master is shifting.

The research used to focus on a focal company within the supply chain that optimizes its performance while discussing the benefits for the chain as a whole, but there have been calls for both supply chain network and company ecosystem views, where it is not merely the individual companies optimizing their own individual performance, but it is the network that is optimized. (e.g. Kinder, 2003) Furthermore, it has become obvious that companies steered by monetary figures are not sufficiently taking into account their societal and environmental impacts, and have been brushing off their negative impacts on the wellbeing of the people and the planet as "externalities". (Klein, 2015) There has been a rise in the corporate social responsibility initiatives within supply chain management practice and the discussion on "social enterprises" has entered the world of management literature. (e.g. Defourny & Nyssens, 2010; Andersen & Sjoett-Larsen, 2009) The (demand-)supply chain should not merely add value to the members of the chain through the deliverables, but the organizations form a network that should increase the wellbeing of people and planet as a whole, as the public sector has not been able to offset the negative "externalities" created by the companies.

Humanitarian logistics and supply chain management is one of the fields challenging the "classical", yet relatively young, conceptualizations of a supply chains focusing on a commercial company and its performance. While efficiency and effectiveness continue to be useful concepts in eliminating waste of precious resources in disaster situations where scarce resources are matched to answer urgent humanitarian needs, the efficiency and effectiveness of the supply network should serve the survival of those affected by the disaster. (Tomasini & van Wassenhove, 2009; Kovács & Spens, 2007)

Paying attention to the underlying purpose of disaster relief is increasingly important, as more and more commercial actors participate in the provision of disaster relief – either as suppliers to NGOs, as well as pro bono. (Balcik et al., 2010; Ergun et al., 2010) Where governments have their responsibilities towards their citizens dictated by their constitutions and humanitarian NGOs act under the humanitarian principles, especially as the supply network of aid gets more complex, it is important to integrate the actors providing disaster relief aid under the wellbeing of the community to be aided. There has been a lot of intent to foster collaboration within the disaster relief. (McLachlin & Larson, 2011; Balcik et al., 2010)

The stages of disaster relief are interrelated and feed-back to one another. (Maon et al., 2009) While there are no clear cuts between the phases, the network of actors that supports the disaster-affected community transforms over time, as do the priorities of the disaster relief network as a whole. While in the immediate response phase the priority of the aid providers is to alleviate the suffering of the most vulnerable ones by fulfilling the basic needs, from water to healthcare, with time the focus and actors shift. NGOs that aim at alleviating immediate suffering move on or turn into development aid providers, the government-provided shelters shift towards insurance company funded housing reconstruction and the people affected try to resume with their lives.

Relatively little research within humanitarian logistics and supply chain management focuses on the reconstruction phase. (Kunz & Reiner, 2012) While the reconstruction phase may not share the same urgency as the immediate response phase, the inequalizing effects of a hazard continues to evolve. The pre-disaster socio-economic vulnerability is connected to the possibilities for the disaster-affected people to fulfill their needs. While disaster reconstruction can encompass a variety of parts, from intangible to tangible, physical housing reconstruction is important for the people affected by a disaster. The need for a shelter is connected to the other needs: in addition to shelter a home in a reconstructed neighborhood can provide a place to prepare food, access to clean drinking water and security.

How housing reconstruction supply network develops and functions is not only related to a specific disaster or its general societal setting, but other factors such as regional socio-economic inequality affect how the reconstruction plays out. The categorization to informal and formal settlements represents one dimension of socio-economic inequality. In the following chapter vulnerability and resilience of disaster-affected communities is discussed with respect to informal and formal settlements. The chapter discusses vulnerability and resilience of communities in order to connect the overarching aim of disaster relief and reconstruction.

Vulnerability, resilience and (in)formality of settlements

Where disaster relief discussion often revolves around the aid coming top-down from external institutions and organizations, the community resilience literature draws the focus on the strength and empowerment of the communities in rebuilding their lives. (e.g. Norris et al., 2008; Manyena, 2006) The idea of community resilience reaches beyond the physical domain and an individual. Community attachment, for example, is positively linked to the health of communities following disasters. (Cope et al., 2013) Furthermore, many communities have context specific ways of living and rebuilding their lives in the aftermath of disasters. Culture insensitive aid that aims to “build back better” can be viewed as an intrusion. Some indigenous communities and traditional institutions, for example, have sustainable and effective ways of disaster resilience and there are increasingly calls to integrate the indigenous knowledge into academic disaster risk reduction literature. (Mercer et al., 2010; Manyena, 2014)

However, the fact that a community has resilience arising from within doesn’t mean that it or its people wouldn’t be vulnerable in the socio-economic system that they are embedded in. Disaster is a hazard with a social context and in the social context both structure and agency matter. (Davidson, 2010) Agency of a community can’t push through all the man-made boundaries and socio-economic inequality means that people have differing degrees of power to control their own fates. Ferdinand et al. (2014), discussing their research across four island states, argue that communities that lack financial resources can have strong disaster management mechanisms, but these mechanisms are also a barrier to engaging with other organizations over vulnerability reduction.

Both disaster resilience and disaster relief literatures focus rightly on discussing the most vulnerable ones: the ones whose lives and livelihoods are at the greatest risk of devastation due to hazards. Like resilience, the concept of vulnerability, has a variety of interpretations, but in this research proposal we refer to socio-economic and environmental vulnerability, where the environmental aspect refers to the risk of hazards proposed by the surrounding physical world. While many authors (e.g. Cutter et al., 2003) argue that economic factors are part of social vulnerability, by referring to socio-economic vulnerability it is here highlighted that while vulnerability is a social phenomenon and the institution within which disaster relief and resilience is discussed is the one of neoliberalism. (e.g. Klein, 2008, Harvey, 2005) Within this context social and economic inequality is increasing (Chomsky, 1999), yet economic reasoning forms the raison d'être of also disaster relief and money ends up being the quantifier of human suffering.

And indeed, while inequality takes many forms and shifts shapes, it is the economic dimension of inequality that gets the spotlight. The United Nations' 2030 Agenda for Sustainable Development starts its preamble with stating that the agenda "is a plan of action for people, planet and prosperity. It also seeks to strengthen universal peace in larger freedom. We recognize that eradicating poverty in all its forms and dimensions, including extreme poverty, is the greatest global challenge and an indispensable requirement for sustainable development." (United Nations, 2015, p. 1) Economic inequality is also tightly bound to the discussion on disaster resilience, especially on the topic of physical infrastructure. The CRED Report from 2015, The Human Cost of Natural Disasters, states that lower-income countries experience greater damage to housing, health facilities and education infrastructure. The report goes on to add that while the high-income countries suffered similar number of disasters as the other income groups between the time period 1994 to 2013, only 3% of damaged housing occurred in these countries, for example due to higher building standards. (CRED, 2015)

The above references highlight how the economic wealth of a country – or a community – is connected to "sustainable development", the availability of disaster-proof infrastructure and further its disaster resilience. It is undeniable that in disaster resilience money is linked to power over one's own fate, as well as that of one's community. For example, people considered as poor in their economic setting lack the financial resources for "hazard-proof" land to build on, safe materials to construct with and insurances to secure their back. In the case of a disaster, they may not afford to relocate to a suitable place. (Ferdinand et al., 2014; Barrios, 2014) Furthermore, instead of preparing for future disasters, their minds may be focused on every-day survival – and upon a disaster, these economically hard-pressed communities end up manifesting their agency through acceptance instead of control. (Stephens et al., 2009; Stephens et al., 2013)

While the connection between economic inequality and vulnerability exists, the conversation stuck on staring at poverty figures may not always address the concerns of the most vulnerable. While many of the sources of disaster vulnerability are connected to the prevailing economic institution(s), reducing poverty in numbers – through for example staring at incremental minimum wage figures or the amount of people under an agreed poverty line – does not necessarily translate into disaster resilience of the people, their ability to pull together and pull through a disaster. One of the ways in which staring at the financial figures or reflecting against neoliberal idea(l)s fails to address the real issues, is portrayed by the discussion on disaster resilience in informal settlements, in comparison to formal settlements.

An *informal settlement* and a *slum* are concepts that appear often side by side and are used relatively interchangeably. (IFRC, 2010; United Nations, 2014a; United Nations, 2014b) According to UN-Habitat's webpage (accessed in 2016) the United Nations categorize a neighborhood as a slum based on the following five characteristics:

1. Inadequate access to safe water
2. Inadequate access to sanitation and infrastructure
3. Poor structural quality of housing
4. Overcrowding
5. Insecure residential status

Within the urban contexts, the people living in the slums or informal settlements are considered to be in the socio-economically and environmentally vulnerable position. Even within an economically wealthy country the building standards and other official disaster resilience activities rarely extend to the informal settlements. From the point of view of the surrounding society, the people in the informal settlements don't exist: they are not part of the census, are not entitled to public services and the disaster resilience plans rarely prioritize them. Yet they are often recognized to be the most vulnerable ones of the society – and hence in the need of the most help in the aftermath of the disasters. (e.g. IFRC, 2010)

However, even if the informal settlements may not *legally* exist or have the state's support, it doesn't mean that they and their people would not exist. For example, in terms of land relations people can have property through social relations in the context, while lacking the property rights enforceable by the state. (Razzaz, 1993) When there is no public system for the informal settlers to rely on, it is the community that provides the support. The states may try to get rid of informal settlements through eradication. But if the people living in the informal settlements make a scant living in absolute terms, a switch into a formal settlement can actually reduce their ability to look over themselves as the formalization may come with a long-term commitment to costs – such as electricity bills and property rents – that are unfeasible for those with an unpredictable and scant income. (e.g. Huchzermeyer 2011, Hillier et al., 2000)

Another challenge to the idea of "development" through integration perspective is formulated by Shatkin (2004) who argues that despite the housing crisis in globalizing cities of developing countries urban planners have forgotten the informal settlements as they "have consciously abandoned place-based poverty alleviation efforts based on the rationale that they are no longer tenable in the global era". (p.2469)

Chandler (2014, p.48) in his paper on how resiliency-thinking is challenging neoliberalism writes that *"neoliberalism as a governmentality sought to govern complexity through instrumentally intervening in interactive social processes to adjust or transform them from the position of the knowing liberal subject, able to balance the levers of the market and the state in order to direct and set goals",* (p.63) whereas *"resilience-thinking -- is a radical critique of the knowledge claims of actually existing neoliberalism, suggesting that the hierarchical causal structure and assumptions of socially determined interactive outcomes still clings too much to a liberal modernist ontology."* Whether resilience delivers, remains to be seen.

So when some authors on disaster management set out to decrease the vulnerability of informal settlements through primarily legitimizing and improving the informal settlements and slums (e.g. El-Masri & Tipple, 2002), the authors are likely to think of resilience from within the neoliberal framework, where top-down bureaucracies frame the logic of possible outcomes. However, the linear idea of first formalizing informal settlements in the eyes of the bureaucracies, then reducing poverty and finally reconstructing for resilience may make us blind to some of the possibilities of resilience thinking. The existence of the informal settlements is often historically connected to oppression, be it colonization or another form of political marginalization. Smith (2012) on her book "Decolonizing methodologies", writes how the history and research written by Westerners explains the indigenous people as the "Other" and marginalizes the indigenous peoples' power. Similarly, if the discussion on the resilience of communities starts by framing the informal settlements as contemporary legal and economic issues from the point of view of the institutions that are at the heart of the socio-economic vulnerabilities, this cuts the connection to the past of the communities, writing their history, present and future from the point of view of the institution external to the community.

Methodology

The paper builds on an abductive case study with a critical realist touch. (Dubois & Gadde, 2002; Wynn & Williams, 2012) The data was collected in Valparaíso, Chile, between the time period January 2015 and December 2015 on the reconstruction after the devastating Great Fire of Valparaíso that happened on 12th of April 2014. This paper relies on field notes on interviews and field visits, and is going to further worked on with the transcribed interviews.

The interviews included people from different organizations – from the Chilean navy, Armada, to the municipality on to aid organizations - that participated in the disaster relief efforts and especially within the sector of housing reconstruction. The interviews were both in Spanish and English, depending on the preference of the person(s) interviewed. Many of the interviewed from the side of organizations had had a university education. Hence while they were speaking about the affected communities, this may have created a bias. Furthermore, many of the people interviewed associated the word *desarrollo,* translated as development or progress, with the country of the researcher, as well as the notion of a very good school system. These associations were likely to shape the responses that the interviewees gave. The Northern habitus of the researcher also may have in other ways stirred bias for example in the hills of Valparaíso.

The fire of Valparaíso provided an excellent case study to study disaster reconstruction taking place a socio-economically unequal society, where both formal and informal settlements have their communal identities connected to the hills, the *cerros*. Chileans are frequently faced with various disasters such as earthquakes, tsunamis, mudslides, volcano eruptions and wildfires. Valparaíso, a city on the Chilean cost, is affected especially by tsunamis and earthquakes. The Chilean housing infrastructure is built to be earthquake prone and people in Valparaíso are accostumed to the risk of tsunamis. However, while small-scale urban fires and larger forestal fires are common in the region, the scale of the urban-forestal fire in April 2014 really tried the resilience of the Valparaísoans.

Valparaíso rises from the sea to the hills, *cerros* and these hills have strong neighborhood identities and people are for example proud to support. The city also portrays the economically polarized Chilean society, where the wealth and political power of the neighborhoods drops towards the tops of the hills. On the tops of the hills reside the *campamentos*, the economically poor informal settlements. These neighborhoods are not part of the census and do not officially exist as part of the city. While also other current and past settlements of the port city have a history of being first *tomas* – claimed land, informal settlements – the word *campamento* has a more impoverished connotation. The two articles on the Valparaíso case are illustrated in the following chapter.

Valparaíso and the (in)formality of settlements

In the Latin American context Chile is a wealthy OECD country. However, Chile is one of the most economically unequal countries in the world. (e.g. Agostini & Brown, 2010) This is reflected also in the city infrastructure of Valparaíso, where the housing shifts from the sturdy structures and maintained roads closer to the *plano* - the flat part of the city where the central business district and the port lye – towards the informal settlements that reside on the top of the hills. In Chile, two words refer to the informality of the neighborhoods: *toma* and *campamento*. *Toma* might be translated as a "claim", where *campamento* comes close to an "encampment". The words have slightly different uses and carry slightly different associations depending on the part of the country. While the informality of the settlements is connected to socio-economic inequality and the informal settlements associate with the low income classes, the matter is not straight-forward.

Campamento often refers to a settlement that is expected to be temporary. The people living in a *campamento* often work in a city, but lack the resources or connections to secure a formal place to live in. They may have come from outside the urban region, or there may be traces of political marginalization involved. There is a dose of "exclusion" entwined into the word. *Campamentos* reside often in the periphery of the city. Their residents may be waiting for the government provide them land or enough support, or they may be gathering momentum or means to organize themselves. In terms of associations, the word *slum* in English carries similar attitudes, as the word *campamento* - at least for those who do not live in a *campamento*. The word *campamento* has similar notions in Valparaíso as in the rest of the Chile.

The word *toma*, on the other hand is loaded with more agency and defiance than the word *campamento*. The word *toma* is referred to by some Valparaísoans as the way and process of constructing new houses in the city: that people find a place, preferably close to their family, to construct a house and advance with the construction ahead of the legal process. The formalization of the house may lag the construction. This may concern a house, or a whole neighborhood. This *toma* construction process is not bound to the education level or income level of the residents nor the formality or informality of their livelihood, but it's rather a way of doing things in Valparaíso. There are neighborhoods whose houses look the same and "formal", yet on paper and from the perspective of public planning and services, they differ.

The lines between the informal and formal settlements are blurred. At one extreme, an informal settlement, a *campamento*, refers to a neighborhood where people don't own the land they have built their makeshift housing on, where people don't have formal jobs, but rather work as informally paid *nanas*, househelp, or in construction. The people living in the informal settlements are not part of the census and the public services don't reach there – the services provided by the government and municipality come mostly in the form of aid, as formally the neighborhoods don't exist. The education, health care, garbage collection and public infrastructure that people have access to – from access to water to road maintenance – are of poor quality, if they exist. As the people living in the informal settlements lack access to public services and may be self-employed, they rely rather on their family and place-based community to provide them a safety net in their life, from children's day care to construction. The precarious life means that people are focused on making the ends meet on a daily basis.

At the other extreme end of the formality scale live the people whose livelihoods and properties are formal. They have a formal employer, own their property, have access to public, private or semi-private basic services from city infrastructure to education and afford to pay their electricity bills. Their social connections reach typically over a larger geographical area and their safety net reaches beyond their families and neighborhoods. Furthermore, access to internet and its communities can provide a further resource in the aftermath of a disaster to those who have access to it.

However, the lines are blurred. People living in informal settlements may have a formal employment and a livelihood that leaves them well of. Meanwhile, people living in formal settlements may have no formal employment and no means to pay the bills associated with the formal settlement, for example electricity, leaving them scarcely money for food. The public services may not have clear border and the public support may come in different forms. While socio-economic inequality is tightly connected to the discussion on informal and formal settlements, the connections are not straight-forward. For example, an interviewee that worked with disaster resilience programs utilizing social media, such as Twitter, said that they had discovered was that social media was used by all income classes in a case of disaster. In comparison to expensive phone calls, the social media messages were seen as more affordable. However, he wasn't sure how this related to the informal settlements.

Unfolding of the disaster of the Valparaíso fire 2014

The fire of Valparaíso 2014 started on the 12th of February of 2014 of the Chilean summer. While forestal fires are common during the summer and small urban fires were common in Valparaíso, the scale of the fire earned it the nick name "El Gran Incendio de Valparaíso". The fire affected eight hills of over three dozen hills of Valparaíso, leaving 15 people deceased, 12 000 people affected and over 3000 homes destroyed. (REDHUM, 2014) There were various formal and informal explanations given for the causes of the fire – from the land dried up by Eucalyptus plantations to the garbage that had accumulated to the ravines between the hills of Valparaíso on to birds that were sitting on an electricity line catching fire.

The fire caught a lot of attention in the region and in the Chilean media. While Chileans and Valparaísoans are used to frequent earthquakes and tsunamis, the fire caught them of guard. Donations and volunteers joined in the immediate response efforts. However, some weeks after the fire the media moved on to focus its coverage on other disasters and only some of the volunteers continued working with the reconstruction. While the phases of disaster relief for the community are intertwined, in the case of the Valparaíso fire, the shift from the immediate response phase to the reconstruction phase was clear for the officials, who shifted the resources from disaster relief to disaster reconstruction at a specific time. During the year 2015 when the data collection was performed the affected communities of Valparaíso were considered to be in the reconstruction phase. While same actors – from the central government and municipality to NGOs – were present in the reconstruction processes of the informal and formal neighborhoods, there were a number of differences as well.

Housing reconstruction supply network and community resilience in the informal settlements

The fire ravaged especially the tops of the hills where the *campamentos* reside. The people living there who didn't have social connections outside their neighborhood looked for shelter provided by the government in *albergues*, shelters*:* schools and gyms that were taken over for the purpose. While the shelters provided a roof for the ones who had just lost their homes and potentially their livelihoods if they were self-employed, people wanted to return to where their homes and communities used to be. Firstly, as the people had no legitimate claim to their terrain, they feared that if they would not guard the piece of land where their and their family's homes had existed, they might get evicted or someone else might claim the land. Secondly, the *albergues* weren't always that safe, as the disaster had brought out violence and women without families were vulnerable to rapes.

The officials, from the side of municipality and the central governments' representation, provided aid to the *campamentos* to help in the immediate aftermath and reconstruction, with volunteers pitching in. Meanwhile, the Chilean Navy worked together with the communities. The main challenge for delivering the immediate relief – food and water, among other things – was proposed by the geography. Reaching the *campamentos* on the top of the hills required either for the aid personnel and volunteers to climb up the burned hills, with the narrow streets full of remains left by the fire, or to circulate the whole city to enter the hills from the highway behind the hills. Furthermore, on the top of the hills where there hadn't been running water even prior to the disaster, neither the affected nor the volunteers had access to water unless it was brought. Animals, from dogs and cats to donkeys and horses used as labour, that had survived the fire also required water. When the people first received food aid the lacked a place to cook and volunteers helped in that too, bringing cooked food from the city below.

People all over the country were collecting donations, mainly clothes, to provide for the people affected by the disaster. However, especially in the *campamentos* people were very concerned with not leaving the plot where their home had resided, so that it wouldn't be claimed by someone else. This was seen as one of the reasons why the cloth donations that reached the *campamentos* started gathering on the narrow streets: people didn't consider it as a priority to go look for clothes. Furthermore, they wouldn't have had a place to store them in. Hence, already in the immediate aftermath the fulfillment of the basic needs became very much entangled with having a shelter, a house, a home. A house with the most basic facilities would allow for preparation of food, would provide shelter for a family and potentially its animals, and a place to store the possessions. The role of the housing was emphasized in the data, but this may have partially been due to the fact that the interviews took place in the reconstruction phase.

During the field visits that took place in April 2015, one year after the Valparaíso fire, many of the makeshift houses in the *campamentos* affected by the fire had "bounced back". Some considered this self-organized infrastructural resurrection as a sign of resilience: that the ones that had had the least were able to get back to the situation where they had been. The materials used, such as corrugated iron, often showed the signs of the fire, while also new materials such as ply wood were visible. Here and there were mediaguas, as Chileans call the pre-fabricated wood-panel and plywood houses, or their parts provided most likely by aiding organizations. However, while there were houses where other houses had resided, this did not mean that the community had recovered or been resilient. A house in a place of a house did not necessary mean that the people that had lived on the plot had returned and rebuilt their lives, and were able to continue their lives in the "new normal" without struggles set by the hazard. The people may have lost the land they and their extended family used to live on and forced to move on, or they may have taken or been offered an opportunity to locate to another place. If the people there had been self-employed, for example in construction or as home help (*nanas*), the fire may have caused a disturbance in them earning their livelihood and forced them to seek other forms of income elsewhere or delayed their reconstruction process – or reconstruction process may have disturbed their ability to earn a living.

One of the discussed ways of providing disaster relief for people living in the informal settlements in the reconstruction phase was formalization of the neighborhoods, so that the people would have the right to the land they had lived on. Every now and then the city formalizes neighborhoods through setting up a new *población*. This formalization, where the officials would (if necessary buy and) sign the property in the name of the person or family that had been living in the plot, was speculated to happen in some of the affected neighborhoods. This would have officially included the neighborhood officially in the sphere of public services: giving the neighborhood more voice and the families the security of having their land. For example, as the people in the informal neighborhoods are not part of the census, the bus routes don't reach the places as the population living there doesn't officially live there. The same is true for example with road maintenance and garbage collection and other services that are usually considered as public. This is important to note, as the narrow roads hindered the extinguishing efforts made by the *bomberos*, firefighters, and other disaster relief actors and the garbage that was gathering in the ravines between the hills of Valparaíso was considered having accelerated the fire. Hence the formalization of neighborhoods can be speculated to lead to a reduced risk of another fire facing the neighborhood. Furthermore, in Chile the neighborhoods use their voice politically through *Juntas de Vecinos*, neighborhood organizations and the informal neighborhoods cannot have an official JV representation, but rather a committee that has a similar function. Hence the neighborhoods needs might be better heard.

However, if the people living in a *campamento* earn a very scarce living and barely afford to eat the basic bread, their living wouldn't likely be able to cover the costs following in the wake of formalization, and their place-based social network, with family members and neighbors might be scattered in the aftermath, the formalization might lead into reducing the risk and vulnerability of the infrastructure to disasters, while the socio-economic and especially vulnerability of the lives of the people might actually decrease. Furthermore, the ones working to earn their property with their incomes it might feel unjust if the criteria for formalization is not clear.

In addition to the self-organized resilience, a variety of different NGOs and governmental organizations participated in the reconstruction and were also involved in providing activities related to the future disaster risk reduction. The risk reduction schemes tried to teach the locals in lowering the geography-related risk through actions taken, and the measures involved for example hiring community members to projects where they acted as the workers in e.g. managing the forestal landscape or organizing ways to deal with the garbage. These activities spun across neighborhoods.

A variety of NGOs participated in the housing reconstruction process. Two NGOs present on the burnt hills highlight the variety of NGO perspectives on the reconstruction in the *campamentos.* First one is a large NGO that works in the Latin America. In Chile their focus in on getting rid of the campamentos and aiding people living in the *campamentos* in reconstructing their lives. They work with a community that they have chosen through their collaboration model and a long-term commitment. In Valparaíso they were involved with an affected community prior to the disaster, so the in the aftermath of the disaster they focused on the neighborhood that their workers had connections with. While some saw the model as a great way to take the community's view into consideration, others saw that the community wasn't presented as a whole in the process, but rather it was the organizations pick and view on who the community was. Another criticism that was often raised about many organizations aiding in the reconstruction was the small size and quality of the *mediagua* shelter provided. The *mediaguas* put fast together from panels that were often meant as a temporary solution would turn in time into a permanent one. At the time of the fire and during the visits it was April and the season was changing towards the winter. People were at the time especially concerned how the temporary turned permanent solutions would weather the cold.

Another NGO was more of a project started by a few young bioconstruction entrepreneurs. They saw the reconstruction following the fire in Valparaíso as a good way for them to provide their expertise to the community in need. At the same time, they saw it as an opportunity to teach the people in the *campamentos* a housing reconstruction technique that would rely on the local resources - the dirt of the Valparaísoan hills being a vital component. This way they believed they would reduce the community's reliance on materials that they would need to buy from outside the community, from companies making a profit. Through their acquaintances they found people that were considered to be in a grave need of housing. They raised funding through their contacts and through a funding website and built three hexagonal houses and 70% of an auto-sustainable "Earthship" house. However, the funding ran out partway of the reconstruction and they weren't able to complete the Earthship house. Furthermore, the working with the beneficiaries didn't go as smoothly as they had hoped. The beneficiaries didn't share their vision and participate in the reconstruction efforts as the people of the initiative had hoped.

Housing reconstruction supply network and community resilience in the formal settlements

The officials, municipality and the central government with its local representation, supported both the formal and informal settlements in the aftermath of the fire. In Valparaíso very few had an insurance: insurances were considered very costly in comparison to the living the people were making. Hence both in the informal and formal neighborhoods the role of the aid provided by the municipality and the government were vital.

For the people that were able to prove that they owned the property they had built in, there were three main options possible with the official support: to have a house constructed for them (they could choose from a few alternative designs), to have support for construction or for renting somewhere else. The housing support was allocated per household. This sometimes led to confusions. In Chile divorce became legal in 2004 and the separation of couples or families is not always that clear-cut. Hence sometimes the head of the family receiving the housing support ended up being the former partner of a mother with children – leaving the single mother and the children more vulnerable.

Many Valparaísoans are attached to the *cerro* they live on and the neighborhood, and prefer to live close-by their family. In some cases a family owned the property, but had the building permission only for one house, while several family members – for example the children of the owner of the property – may have built their own houses on the property. This meant that in the aftermath of the fire only one house was reconstructed where few had existed.

However, typically, a person or a family living in a formal settlement and having a formal employment, would have his or her social and support network geographically spread out outside their neighborhood, over the city of Valparaíso or the close-by region: they would work outside their neighborhood, have their children go to school outside their residential area and they would have friends also in the other neighborhoods. So while in many cases the devastation caused by the fire impacted extended families, the devastating impact of the fire for their social and support network wasn't complete.

It was length and the bureaucracy of the housing reconstruction process that was making people anxious at the time of the study. The reorganization of the logistics of their lives that they had assumed as temporary was lasting over what they had initially expected and the paper work to be done was taking a lot of time and effort. There were fears about the money for reconstruction running out and the process stalling. Some of the (temporary) homes provided by the officials were considered completely insufficient and some people had combined their own reconstruction with the housing provided by the officials. Some people chose to reconstruct their homes completely on their own with the funding from the government. This didn't necessary let people feel in control over their lives, especially if they took help from external suppliers. During this time the demand for the professional constructors peaked and the high demand led the contractors to behave opportunistically and even scams took place.

Discussion: Housing reconstruction supply network and community resilience in the aftermath of the Valparaíso fire 2014

The table below summarizes the different ways in which the communities were supplied with housing in the aftermath of the fire of Valparaíso 2014, and how the housing reconstruction was connected to the resilience of the communities. The table separates between informal and formal settlements, but between the two typical examples a variety of housing situations exist and many of the schemes, for example on disaster risk reduction, arched over both the formal and informal neighborhoods. Furthermore, for example the involvement of the central governments local representation was felt in both the formal and the informal neighborhoods.

However, also differences exist. While the disaster risk reduction was in the formal settlements embedded in the planning of the neighborhoods and supported by the public services – such as the garbage collection – in the informal settlements a lot of effort was put to teach the people ways of reducing their own vulnerability to disasters on their own. While all the Valparaísoans had a relatively high attachment to their neighborhoods and often lived close to their families, in the informal settlements the role of the place-based community and social network was emphasized, while people in the formal settlements had a geographically wider community.

From the perspective of the housing supply network the people living in informal settlements were either self-organized constructors or beneficiaries, while the people in the formal settlements were considered and considered themselves more as end-users of the housing provided. In the formal settlements the external support in housing had more a tone of a "right" instead of "aid" to it, which was the case with the informal neighborhoods. While from the external-to-community actors the officials played an important role for both the informal and formal settlements, especially in the informal settlements the role the NGOs was highlighted. In many cases the NGOs or other aimed at empowering the people living in the *campamentos* through providing them housing or a technology to construct housing.

While the idea of development, of better future preparedness to urban fires and other disasters, was in the air for both the formal and informal settlements, in practice the formal settlements seemed to be more directed towards being built back to status quo. Meanwhile, in the informal settlements there were a variety of initiatives, technologies and ideals brought in that aimed at empowering the community and improving not only their disaster resilience, but also their living conditions. This was especially the case with organizations committed to poverty reduction and long-term work. However, in the informal settlements these initiatives were rather fractional than systemic.

Prior to the disaster the houses had been of differing qualities between the informal and the formal settlements. In the aftermath, some of the houses in the *campamentos* were constructed from the burnt material, such as corrugated iron, and combined with new materials. Also plywood or wood panel shelters, or pieces of them, were used to reconstruct, or were provided by the NGOs. Meanwhile, if the people in the formal settlements didn't choose to move out, the materials of the houses in the formal settlements depended on whether they opted for a house provided by an official, with a restricted selection of saploons, or whether they constructed with their own lead.

While the reconstruction of the informal settlements infrastructually to a status quo can be seen as a sign of disaster resilience of the people socio-economically most vulnerable, the infrastructure does not tell the whole story. If the people living in the informal settlements are not part of the census, people may be displaced from where they used to live and lose their geographically centered social network and may have lost livelihood due to reconstruction efforts. Meanwhile, the fact that people in the formal settlements resumed with their day jobs and daily lives, despite the interruption could have been considered as personal resilience – while the place-based community had not yet been restored, as the construction was depending on third parties.

Table 5 Comparing the disaster supply networks and the resilience of the informal and the formal settlements

	Formal settlements	Informal settlements
Disaster risk reduction	Included in the planning of the neighborhood, public services	Initiatives to teach people
Community	neighborhood attachment, but also geographically scattered due to employment and other activities outside the neighborhood	Place-based, with the family and neighborhood near-by providing a support network for the family
The role of the individual households in housing reconstruction	The end-user	Self-organized constructors or beneficiaries
The housing reconstruction with the support of an external organization is considered	a right	aid
The central external actors involved in the reconstruction	The municipality and the government's representation vital	The municipality and the government's representation and NGOs
The role of external actors to the community	Suppliers and "insurers"	Benefactors, empowerers
The dominating ideology of the suppliers	Supplying housing, restoring status quo	"Build back better" through a variety of different methods and resources brought and

		taught from outside the community, poverty reduction
The materials	The municipality had a selection of housing models available with set materials, or the people could choose their constructors themselves, with the materials	The old construction materials recycled after the fire, cheap congregated iron ubiquitous, mediaguas built from wood panels provided by NGOs, different types of innovative techologies
The manifestations of vulnerability	Feeling out of control while waiting for the reconstruction and organizing the logistics of everyday life	Loss of lives and livelihoods with the housing, loss of claim to “one’s” terrain
The manifestations of resilience	The recovery back to everyday routines despite the re-organized everyday life due to loss of housing	Fast recovery of the makeshift housing, the tightness of the place-based community

Conclusion

Efficient and effective use of resources is vital in the humanitarian context and wasting resources can result in unnecessary lives lost, and the learnings from the commercial side have proved useful. (Tomasini & Van Wassenhove, 2009) However, while the humanitarian system is growing in size and improving, its instrumental developments have not always resulted in an increased long-term wellbeing of the communities considered as vulnerable. Studying disaster reconstruction supply networks can help focus the discussion on the long-term aspects of disaster relief aid and embed the discussion on socio-economic inequality into it. Socio-economic inequality lies at the heart of definitions of (disaster) vulnerability, so addressing vulnerability is to address inequality.

One of the manifestations of inequality in the urban contexts is the division of the cities into formal and informal settlements. This paper studied the reconstruction in the aftermath of the fire of Valparaíso with respect to the (in)formality of the neighborhoods affected by the fire. Studying the differences in supply of housing in the aftermath of the Valparaíso fire 2014 highlighted how the resilience of the community with respect to the housing reconstruction depends on the depth to which the place-based community serves a social support network for the people living in it. While in the formal settlements the social resilience was on the surface not that tightly bound to the place, especially in the informal settlements the place and the social connections bound to the place were an important part of the recovery and resilience.

While also in the context of humanitarian disasters measuring the effectiveness and efficiency of the supply chain or network can help reduce waste in providing the beneficiaries what they need, the supply chain may not be geared towards the needs of the most vulnerable ones. This may be the case especially in reconstruction, where the actors responsible for the reconstruction are often the same ones that act as constructors in the status quo. Mapping the disaster reconstruction supply network in the aftermath of a disaster with respect to informal and formal settlements can aid in focusing the resources where they best serve the communities in their recovery – and this action also teases out the inherent inequalities of the system of disaster reconstruction. Measuring the effectiveness of a housing reconstruction supply chain may be irrelevant, if the ones worst affected by the disasters and their resilience falls outside the scope of study.

If in the aftermath of a disaster, an actor external to the community of an informal settlement, aims to help the people of the community, they need to be conscious of the dynamics of community resilience in the informal settlements. If the idea of “building back better” focuses on having the people living in less disaster-prone housing, the tools used might involve dispersion and/or formalization of the community. While people might have safer houses as a result, their capabilities to move on with their lives may have been actually hindered as they may have lost their social safety net. Furthermore, even if people in informal settlements earn very little in absolute terms and formalization might be argued to lead to steps that increase the people's absolute income level in the long-term, their ability to satisfy their basic needs may have actually been hampered compared to the pre-disaster conditions. As the aim of humanitarian logistics and supply chain management is to "aid people in their survival" (Kovács & Spens, 2007, p.101), this is a crucial thing to note.

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MANAGING UPSTREAM-DOWNSTREAM DICHOTOMY IN EUROPEAN RIVERS: A CRITICAL ANALYSIS OF THE LAW AND POLITICS OF TRANSBOUNDARY WATER COOPERATION IN THE EUROPEAN UNION

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Abstract
While the European Union has one of the most extensive and sophisticated supranational water policy worldwide, its transboundary governance framework has certain structural deficiencies that may eventually give rise to significant cooperation gridlocks over shared rivers. These include the procedural nature of the cooperation obligations under EU law, the ignorance of water quantity management issues, the lack of institutional mechanisms to manage hydro-climatic variability and the patchy system of transboundary water dispute settlement. These lacunas suggest an increase in the likelihood of lengthy bilateral water disputes with high social and environmental costs within the EU.
Keywords: shared river basins, hydro-politics, European Union

Introduction: why transboundary waters matter

All living things run on water. While the amount of accessible freshwater in the world is limited and remains constant, it has to satisfy the ever growing demands of an ever growing number of users, be it human beings, the economy or the natural environment. Moreover, the various human-induced pressures of the Anthropocene – population growth, urbanisation, climate change, globalisation – are leading to a massive degradation of the quality and quantity of freshwater resources worldwide. As a result, by 2030, the world is projected to face a 40% water deficit if current trajectories remain unchanged (UNESCO, 2015).

Consequently, water security in the broadest sense of the term will be one of the critical questions of development, peace and stability in the 21st century. Not surprisingly the World Economic Forum has repeatedly identified water as the number one global source of risk in terms of impact (World Economic Forum, 2015). The US National Intelligence Council in a recent report also concluded that “water may become a more significant source of contention than energy or minerals out to 2030 at both the intrastate and interstate levels” (US National Intelligence Council, 2012).

Changing hydrological conditions are further complicated by geography of water: around 47% of the Earth’s surface waters lie in basins shared by at least two countries. These basins are home to some 40% of the world’s population and account for about 60% of the global river flow (Wolf et al., 1999). Consequently, the bulk of world’s unfolding water crisis will have to be addressed and solved in an international context.

Collective action problems of transboundary watercourses: why cooperation matters

While geography defines the possibilities for where, how and when water can be developed and used (Elhance, 1999), political boundaries impose serious constraints on the choices available to governments to actually make use of these possibilities. Transboundary water relations are burdened by a natural asymmetry between upstream and downstream countries, often coined as “spatial misfit” (Young, 2002).

The downstream motion of water creates externalities that are mainly of a unidirectional character. Changes in the quantity and/or timing of river flow, water quality, river morphology, etc. induced by one riparian can trigger widespread consequences on riverine ecology, irrigation, agriculture, fisheries, energy production or navigation opportunities of other riparian states. Externalities however do not always unfold in an upstream-to-downstream dimension, neither are their necessarily negative (Moellenkamp, 2007). Nonetheless, the spatial misfit of shared river basins automatically gives rise to a number of complicated cooperation problems whose resolution requires the collective action of all concerned riparian states.

Such already difficult cooperation challenges will be further accentuated by climate change as altered precipitation patterns will render future river flow variability outside the bounds of previously observed events. This, coupled with the impacts of other human-induced phenomena such as population growth, unilateral water development and pollution or unbalanced levels of economic development, may seriously test the hydro-political balance all over the world (Giordano and Wolf, 2015).

Transboundary river basins in the European Union

Europe's river basins

The European continent has the highest number of international river basins worldwide. Europe's basins vary greatly in terms of size, hydrological conditions and political complexity. Out of the 69 transboundary basins 39 are shared only by two countries, while the Danube catchment area, considered as the most international river basin worldwide, comprises no less than 19 countries.

The geographical and political fragmentation of Europe results in a very high transboundary exposure for most countries. In 16 European countries more than 90% of the territory is located in an international river basin. Most European countries rely heavily on waters that originate outside their territories. Germany, Greece, Luxembourg and Portugal receive 40% of their surface waters from abroad, the Netherlands and Slovakia 80% while Hungary 95% (Rieu-Clarke, 2009).

The impacts of climate change on European freshwater resources

In its 2012 thematic report the European Environment Agency confirmed the widespread existence and forecast the acceleration of climate change in Europe (EEA, 2012). In the context of freshwater resources the report highlights that over the past decade precipitation has increased in north and north-western Europe, but it has decreased in southern Europe. At the same time snow cover has been decreasing and the vast majority of glaciers in Europe have been receding. The most important impact will be changes in the availability of freshwater, i.e. higher variability of river flows. River flows have already increased in winter and decreased in summer, but with substantial regional and seasonal variation.

For northern Europe projections suggest less snow, lake and river ice cover, increased winter and spring river flows in some parts (e.g. Norway) and decreases in other parts (e.g. Finland), and greater damage by winter storms. For north-western Europe higher winter precipitation is expected to increase the intensity and frequency of winter and spring river flooding. The most severe effects will be felt in Central and Eastern Europe where river flow droughts are already widespread and are projected to further increase with prolonged and more extreme dry periods. Decreasing water availability is projected to exacerbate water stress, especially in Southern Europe.

Moreover, climate change has already increased water temperatures of rivers and lakes, and has decreased ice cover. Changes in stream flow and water temperature have important impacts on water quality and on freshwater ecosystems. Environmental flows, which are important for the healthy maintenance of aquatic ecosystems, are threatened by climate change impacts and socio-economic developments.

In summary: water stress will emerge as a widespread phenomenon and it is projected to worsen where it already exists. Importantly, while such negative quantitative effects can partly be reduced by water use efficiency gains (e.g. in the field of irrigation), these measures will not be sufficient to compensate for climate-induced increases in water stress. At the same time floods and the economic loss due to floods are projected to significantly increase in large parts of Europe.

The law and policy of transboundary water management in the European Union

Overview

As mentioned above, the European continent has the highest number of international river basins in the world as well as some of the most complicated ones. Yet, it has also developed one of the most extensive and sophisticated system of transboundary water governance. Europe is the only continent that has developed an overarching treaty framework: the UNECE Water Convention and its protocols. It also maintains a highly successful institutional system that is specifically dedicated to transboundary collaboration. Moreover, the majority of European countries are also member states of the European Union or candidates for accession. These countries also have to apply the general and water-specific legislation of the EU that, among others, has important implications for transboundary cooperation.

Europe's relative success in managing transboundary water relations is attributable to a number of factors. Except for the Iberian Peninsula, most of Europe's international rivers have, until recently, had abundant flows, not exceeding historic ranges of variability. Also, Europe is largely free from the most common human-induced pressures that seriously complicate co-riparian relations elsewhere: there are no exponential population or urbanisation pressures on most river basins, upstream countries tend to be rich and environmentally conscious with no unilateral water development agenda, etc. There is also a long history of cooperation in most river basins and, at least in the EU, environmental protection is a broadly shared political priority (McCaffrey, 2015).

These favourable conditions however do not prevail in the entire continent. The rivers of the Balkans Peninsula or the large eastern river basins of the continent (Dnieper, Dniester, Don, Volga) are in a much less favourable state in terms of ecological status, institutional protection or political attention.

The UNECE Water Convention

The UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (the UNECE Water Convention) has been developed under the auspices of the United Nations Economic Commission for Europe, the UN's regional cooperation body for the Pan-European region (whose members also comprise the countries of the former Soviet Union, the United States and Canada). The Convention was adopted in 1992 and entered into force in 1996. It has quickly evolved into a full-fledged model platform for transboundary water cooperation. It has two protocols – Protocol on Water and Health, Protocol on Civil Liability – of which the latter is not yet in force. The European Union is a party to the Convention and, as such, it is binding on all of its member states as well as EU institutions.

The Convention requires parties to enter into specific basin agreements and to establish joint bodies (Art. 9). As a framework instrument it does not replace bilateral or multilateral agreements on specific basins or aquifers, rather it is intended to complement their implementation. The core obligations under the Convention include:

- to prevent, control and reduce adverse transboundary impacts on the environment, human health and socioeconomic conditions. Transboundary impact is defined broadly to include effects on human health and safety, flora, fauna, soil, air, water, climate, landscape and historical monuments or other physical structures or the interaction among these factors; they also include effects on the cultural heritage or socio-economic conditions resulting from alterations to those factors (Art. 1.2),

- to manage shared waters in a reasonable and equitable manner using the ecosystem approach and guided by the precautionary principle and the polluter-pays principle (Art. 2),
- to preserve and restore ecosystems (Art. 2, 3),
- to carry out environmental impact assessments, to draw up contingency plans, set water-quality objectives and minimize the risk of accidental water pollution (Art. 2, 3, 14).

The UNECE Water Convention is supported by a robust institutional framework, including the regular meetings of the parties, a compliance mechanism, various working and expert groups and a highly active secretariat. The Convention bodies are engaged in a very broad range of activities, including assessment of the state of water bodies, information exchange, capacity building, etc. The Convention has also successfully ventured out into such new progressive topical areas as climate change adaptation or the payment for ecosystem services.

European basin treaties and organisations

Europe has not only the highest number of river basins in global comparison, but also the widest basin treaty coverage. This is not surprising in view of the fact that the UNECE Water Convention obliges parties to enter into basin agreements and of the active assistance the Convention bodies lend to the development of such treaties. This new body of agreements includes the basin treaties relating to the Danube, the Oder, the Meuse and Scheldt, the Rhine and a series of bilateral water (frontier) treaties between Spain and Portugal, several ex-Soviet member states and their EU neighbours (Trombitcaia & Koeppel, 2015).

The European basin agreements have also established river basin commissions that provide a platform not only for the implementation of the treaties, but also for addressing new challenges that emerge in the basin. Some basin commissions, such as the International Commission for the Protection of the River Danube, run a wide range of programmes that expand the basic activities covered by the basin treaty in a progressive fashion.

The laws and institutions of transboundary water governance in the European Union

The environmental law and policy of the European Union

Water issues in the European Union fall under the broader category of environmental policy under one of the EU’s founding treaties, the Treaty on the Functioning of the European Union (TFEU). It is an important qualification as EU water policy remains subject to the general principles of environmental policy that flow from the TFEU and the EU’s other founding instrument, the Treaty on the European Union.

The objectives of EU environmental policy are defined by the TFEU as follows: the preservation, protection and the improvement of the quality of the environment, the protection of human health, the prudent and rational utilisation of natural resources, and the promotion of measures at international level dealing with regional or worldwide environmental problems (Art. 191.1). To achieve the latter goal the EU and its member states have to cooperate with third countries and international organisations and may enter into international agreements (Art. 191.4). Importantly, these agreements – such as the UNECE Water Convention – form an integral part of the EU’s legal system and, as such, are binding on the EU institutions and its member states (Art. 216.2).

The objectives of EU environmental policy must be pursued in accordance with a number of principles, notably the principle of high level of protection, the precautionary principle, the principle of preventive action, the principle that environmental problems as a priority should be rectified at source and the principle that the polluter should pay (Art. 191.2).

In general, the EU adopts its own environmental legislation through the so-called ordinary legislative procedure, i.e. by the joint legislative act of the Council of ministers, voting by qualified majority, and the European Parliament, voting by simple majority (Art. 192.1). In the context of water policy however there is one major exception to this rule (Art. 192.2): "measures affecting the quantitative management of water resources or affecting, directly or indirectly, the availability of those resources" can only be adopted through a special legislative procedure, where the Council acts with unanimity and the European Parliament is only consulted (i.e. cannot block or amend the legislation as under the ordinary legislative procedure). Arguably, this exception is designed to safeguard member states' sovereignty to regulate the flow of water by way of granting veto power to any member state and by excluding the European Parliament, generally seen as an activist, green force in the joint decision-making process. Even though the European Court of Justice constructs this clause narrowly (case C-36/98, Spain v. Council), it has nonetheless created a situation where adopting EU measures specifically addressing water quantity management has become virtually impossible, with the ultimate result of downplaying quantitative issues in EU water policy.

The water-related legislation of the European Union

The centrepiece of today's EU water law is Directive 2000/60/EC establishing a framework for Community action in the field of water policy, i.e. the Water Framework Directive (WFD). The WFD represents a broad overhaul of the previous water policy and regulatory philosophy: it has either replaced or called for the gradual repeal of 25 years of previous EU water legislation, leaving only a handful of pre-WFD legislation in place.

The WFD lays down a comprehensive framework for the protection and the improvement of the aquatic environment. It has a universal scope covering all inland freshwater (surface and groundwater) bodies within the territory of the EU as well as coastal waters. It also covers wetlands and other terrestrial ecosystems directly dependent on water (Art. 1). Its regulatory approach is based on the integrated assessment and management of all impacts on the aquatic environment, extending the previous chemical focus to biological, ecosystem, economic, morphological aspects and, to a lesser extent, quantitative issues. It establishes environmental objectives for surface waters, groundwater and so-called protected areas (areas designated under other EU legislation for their particular sensitivity for water – e.g. nature conservation areas, drinking water resources, etc., Art. 4). These objectives are summarised as "good water status" that is described by normative ecological and chemical parameters for surface waters and chemical and quantitative parameters for groundwater. Importantly, the WFD considers quantitative issues as "ancillary" to water quality, conspicuously leaving surface water quantity to a regulatory grey zone.

The planning and implementation framework of the WFD is the river basin. Member states are obliged to identify river basins in their territory and assign them to river basin districts. If a river basin is shared by more than one member state it has to be assigned to an international river basin district (Art. 3). The environmental objectives of the WFD have to be achieved through a complex planning and regulatory process that, in the case of international river basin districts, requires the active cooperation of member states (Art. 3, 13). The main administrative tools of member state action are the river basin management plans and the programmes of measures to be drawn up for each river basin district (or the national segment of an international river basin district). Member states are obliged to carry out extensive monitoring of the quality of the aquatic environment along EU-wide coordinated methodologies (Art. 8, Annex V).

The WFD, as its name suggests, provides only a framework for water policy. There exists a range of additional legislative measures addressing various specific water-related issues. The first group of such measures is concerned with various sources of pollution or the chemical status of water. The most important such measure is the urban waste water directive (Directive 91/271/EEC), the single most costly piece of environmental legislation ever to be implemented in EU history. It obliges EU member states to collect and subject to appropriate (i.e. at least biological) treatment all urban waste water (above 2000 population equivalent) and the waste water of certain industrial sectors. Another important source of nutrient input, i.e. nitrates pollution from agricultural sources is regulated by the so-called nitrates directive (Directive 91/676/EEC). It aims to protect surface and groundwater by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices. Discharges into surface waters of the most prominent hazardous substances is governed by the environmental quality standards directive (priority substances directive, 2008/105/EC) that sets limit values for 33 priority hazardous substances and 8 other pollutants with a view to their progressive elimination. The groundwater directive (2006/118/EC) establishes a regime which defines groundwater quality standards and introduces measures to prevent or limit inputs of pollutants into groundwater.

The EU's general industrial pollution legislation, the so-called industrial pollution (formerly: IPPC) directive (2010/75/EU) lays down an integrated permitting system for the most important industrial installations, with strict conditions relating to surface water, groundwater and soil protection. Importantly, it subjects all existing and future permits to a periodic review in light of the developments in the best available techniques, i.e. the benchmark technology and industrial practice. While less relevant in this context, mention must nevertheless be made of the drinking water directive (98/83/EC), the bathing water directive (2006/7/EC), the flood risk management directive (2007/60/EC) or the marine strategy directive (2008/56/EC), all contributing to the broad environmental objectives of the WFD.

Significantly, other EU environmental measures may have important effects on water management. These include horizontal legislation such as the environmental impact assessment (2011/92/EU) and the strategic environmental impact assessment directives (2001/42/EC), the directive on the access to environmental information (2003/4/EC), the environmental liability directive (2004/35/EC), EU nature conservation measures, especially the habitats directive (92/43/EEC).

The EU is also party to a large number of transboundary water conventions, such as the UNECE Water Convention, the Danube Protection or the Rhine Conventions.

Transboundary water cooperation under EU water law

As mentioned above, the WFD follows a basin approach. Consequently, the directive foresees a close cooperation among member states sharing international river basins. As it appears from the Preamble to the WFD, cooperation is not considered as a bilateral (or multilateral) responsibility, rather, the joint fulfilment of the objectives of the WFD is seen as a common European interest. The WFD thus lays down certain procedural requirements and mechanisms member states must observe in the implementation of the directive.

First, member states are generally required to coordinate their efforts aimed at meeting the environmental objectives of the directive for the entire river basin or river basin district. This implies that where a river basin is covered by the territory of more than one member state, it must be assigned to a so-called international river basin. When no agreement is reached on the designation of such international basin, any member state concerned may request the European Commission to facilitate the process (Art. 3.3). Shared river basins must be subjected to the same administrative and institutional regimes as purely national basins, irrespective of their international character (Art. 3.4).

Second, member states must coordinate the management of their sections of the international river basin from planning all the way through implementation, most notably the preparation and execution of their river basin management plans and programmes of measures, the main framework for action under the WFD (Art. 3.4). Consequently, as a priority, member states concerned are called upon to produce a single management plan for the entire river basin. This is, however, not an obligation of result: should the coordinative efforts of member states fail to result in a geographically comprehensive river basin management plan, then riparian governments are merely required to adopt uncoordinated national plans and measures for their respective parts of the international basin (Art. 13.2). Should differences emerge in this context among member states, the Commission may be invited to facilitate (Art. 3.4).

Third, where an international river basin district falls partly outside the territory of the EU, the member states concerned are called upon to establish “appropriate coordination” with the non-EU riparian states with a view to achieving the environmental objectives of the WFD for the entire basin (Art. 3.5). This implies the rather soft requirement to “endeavour” to produce a single river basin management plan in cooperation with the relevant non-EU riparian states (Art. 13.3).

Member states can ensure such coordination through existing international mechanisms or organisations, such as a river basin organisation (Art. 3.4). Indeed, all major European basin organisations have indeed been mandated by their members to ensure the coordination of the implementation of the WFD in their respective basins. In some cases, like the Meuse, a new basin commission has been set up with the specific objective to provide a framework for WFD implementation. The expansion foreseen by the directive beyond the territory of the EU also proved successful as all non-EU riparian states in the Rhine, Danube and Sava agreed to implement the WFD in their respective shares of the basin.

Finally, the WFD introduces a quasi “dispute resolution” mechanism whereby any member state whose water management has been impacted by another member state may report the problem to the affected riparian or the Commission, together with its own recommendations to solve the problem. All the Commission is required to do however is to “respond” to the recommendation of the concerned party within a period of six months (Art. 12).

Other pieces of EU legislation also establish transboundary cooperation mechanisms. The most notable is the floods directive that requires riparian states to assess and map flood risks as well as to develop flood risk management plans. The directive foresees the same type of (rather weak) coordination mechanism as the WFD, urging member states to exchange data and produce a single risk management plan for international river basins (Art. 4.3, 8.2). The directive however contains an important substantive obligation – the only explicit transposition of the “no-harm” rule into EU law – that prohibits member states to adopt such flood management measures in international river basins that significantly increase flood risks either downstream or upstream (Art. 7.4).

In addition, some of the water pollution-related European legislation also contain provisions relevant in the context of co-riparian relations. Uniquely in EU water law, the priority substances directive specifically addresses transboundary water pollution in so far as it exempts downstream member states from their liability to meet environmental quality standards to the extent caused by upstream member states (Art. 6). In a less explicit way, the urban waste water directive recognises upstream-downstream interdependence. If a member state is affected by waste water pollution from another member state, it may notify the latter and the Commission. They are called upon to hold consultations with a view to “ensure conformity with the directive” (Art. 9).

General EU environmental law also creates important obligations for Member States in their co-riparian relations. These include the environmental impact assessment, the industrial pollution and the environmental liability directives. They all establish specific information exchange and consultations procedures to assess, prevent or mitigate transboundary freshwater impacts. These procedures – that are largely modelled on applicable UNECE conventions – constitute the institutional framework of the European implementation of the “prior notification of planned measures” principle of international water law.

Institutions

EU water law, especially the WFD is supported by an elaborate system of political and technical bodies administered by the European Commission that have produced a broad range of guidance and other resource documents, most importantly the Common Implementation Strategy of the WDF(European Commission, 2001).

Member States chief water regulators cooperate actively on a formal basis through the network of appointed national water directors. EU member states also benefit from the vast and well-funded technical apparatus of the various agencies of the Commission, especially the European Environment Agency, that carries out environmental monitoring, data collection and analysis of all environmental media, water included.

Cooperation gridlocks over shared EU waters: is water-peace secured?

The lack of comprehensive EU transboundary cooperation framework: the chance for trouble

EU water law, especially the Water Framework Directive has been universally praised as the most sophisticated and progressive transnational water regime globally (Dellapenna & Gupta, 2008). For its courageous innovations with respect to river basin planning, integrated and holistic coverage of all waters and uses, internalisation of economic considerations, public participation, etc. the WFD unquestionably represents a very high level of ambition that can serve as a model for the rest of the world (Canelas de Castro, 2008).

Indeed, the above description of legal norms and institutional mechanisms might suggest that EU member states are well equipped to withstand the challenges that the Anthropocene is likely to bring into co-riparian relations. In other words: existing European cooperation frameworks guarantee that riparian states can maximise their collective payoffs with regards to the shared river through collaboration.

A closer scrutiny of the political resilience of the current European cooperation mechanisms however reveals that the existing legal and institutional structures leave important gaps that may turn into critical vulnerabilities in upstream-downstream relationships. This is due to the fact that despite all these progressive achievements, the WDF clearly falls short of a comprehensive transboundary cooperation framework – leaving the UNECE Water Convention the sole generic legal instrument in place on the subject –, which can be illustrated by the following structural shortcomings. First, the WFD follows a typical EU approach to environmental policy as it imposes parallel obligations on member states to do the same thing at the same time, instead of requiring them doing things together. This is based on the assumption (hope) that parallel action of states will also eliminate transboundary effects. Undoubtedly, in the case of several environmental problems (e.g. point source pollution) this approach may lead to the desired results. Many water-related problems are however beyond the direct command and control of individual countries by their very nature, thus even impeccable compliance by member states with such parallel obligations may fail to deliver the envisaged outcomes. Second, most of the cooperation requirements are of procedural in nature and contain only a duty of conduct, rather than a duty of result. Third, as already mentioned, the WFD (almost) completely ignores the quantitative aspects of surface water management and, as a consequence, variability management. Finally, the EU's system of water dispute settlement is, at best, sketchy. In summary, the EU's transboundary water regime neither provides normative guidance for some of the most critical issues of water management, nor does it offer a robust platform to solve potential disputes among riparian states. The lack of comprehensive EU transboundary cooperation framework becomes particularly acute in cases where international water law is in clear collision with EU treaty law.

Consequently, some critical weaknesses in the EU's transboundary water governance regime may open the door for cascading measures and counter-measures by member states that can cause prolonged cooperation gridlocks for lengthy periods of time.

Proceduralisation

As described above, EU environmental law stipulates a number of important obligations as to when and what member states must do with regards to shared water resources. These include the prior information on and the joint assessment of projects with significant transboundary impact on water, cooperation in the assessment of international river basins, coordination of river basin management plans and implementation measures, etc. These obligations are, however, almost exclusively of procedural nature reflecting a regulatory philosophy that assumes that the right procedures lead to good decisions (Krämer, 2002). The rare exceptions where EU water law contains substantive obligations on states' conduct vis-à-vis other riparians, do not go beyond a specific adaptation of the "no-harm" rule laid down by the UNECE Water Convention and the UN International Watercourses Convention.

However, the procedures that are supposed to provide the backbone of basin cooperation cover only a small segment of possible interactions among riparian member states. E.g. while EU countries are required to develop joint river basin management plans and programmes of measures, that obligation does not extend to the joint implementation of the plans. Besides, not only is cooperation reduced mainly to procedures, compliance with such cooperation procedures is not supported by robust sanctions. In fact, as described above, if member states fail to come to terms over joint international river basin plans or flood risk management plans, their failure to cooperate triggers no legal consequences whatsoever (Van Rijswick et al., 2010). Finally, even where joint procedures are provided for, they are not broken down to procedural steps (timetables, milestones) or supported by established platforms for consultation (although the European Commission may be invited to help). While basin organisations play an important role in coordinating the planning processes of riparian states, they have powers neither to vigorously coordinate, nor to compel countries to participate in the process. Not surprisingly, the lack of common procedural guidelines and the absence of sanctions, the coordination of basin plans shows a very mixed picture (Baranyai, 2015b).

Water quantity management

Water allocation issues are at the heart of most water conflicts (Wolf, 2009). Nevertheless, water quantity issues are addressed only superficially in EU water law (save groundwater quantity under the WFD and some policy efforts to reduce water demand). In particular, EU law does not contain any norm whatsoever to guide the allocation of water among riparian states of transboundary water courses.

This obvious shortcoming is largely due to the difficulties of the EU to adopt "measures affecting the quantitative management of water resources or affecting, directly or indirectly, the availability of those resources" by unanimity. However, it also reflects a political complacency of the European institutions to address an issue that has, to date, been mainly seen as an Iberian problem (Albiac et al., 2014).

There have been some modest efforts recently to close this gap by way of re-labelling water quantity as an environmental quality issue. The current water policy document of the EU, the 2012 Blueprint for Europe's Waters (European Commission, 2012), recognises the interlinkages between quality and quantity, considering the latter as an important factor in the achievement of good water status. This purely ecological approach is further elaborated in a guidance document issued by the European Water Directors entitled "Ecological flows in the implementation of the Water Framework Directive" (European Commission, 2015). The ecological flow concept however completely ignores the water demand of sectors other than the natural environment.

The EU's self-restraint in relation to water quantity management constitutes a major gap should member states face serious river flow shortages as a result of intensifying climate change or human interventions (e.g. expansion of irrigation to make up loss in water quantities).

Variability management

The EU has developed a broad range of policy and legal measures to address the phenomenon of climate change, including the adoption in 2013 of a climate adaptation strategy. In the context of water management a specific guidance document entitled "River basin management in a changing climate" was adopted in 2009 (European Commission, 2009).

EU law does however not contain any specific mechanisms or procedures to address significant variations in the quantity of water available (let alone adjustment of allocations among member states). This, of course, is not surprising in view of the low status of water quantity questions under contemporary EU water policy. Thus, even though the above guidance document outlines very clearly the quantitative challenges member states face or likely to face in the future, apart from flood management (that is already covered by EU law from a procedural perspective) it does not address transboundary problems in any significant way.

Dispute settlement

The EU has the most effective supranational legal enforcement mechanism in the form of the so-called infringement procedure that can be initiated by the European Commission for any given infraction of EU law by any member state. The procedure may lead to the condemnation of the erring state by the European Court of Justice and the eventual imposition of significant financial penalties (TFEU Art. 258, 260). The infringement mechanism however works top-down between the Commission and the member state concerned and is not designed to adjudicate intra-EU disputes. While member states may also signal to the Commission issues of non-compliance by other member states, the Commission has no obligation to take up the matter. Consequently, the most important general EU enforcement procedure does not constitute an adequate dispute settlement mechanism for transboundary water issues.

Neither does the WFD offer any robust means to solve bilateral water disputes. Although a member state that has identified "an issue that has an impact on the management of its waters but cannot be resolved by that member state" – a euphemistic description of a transboundary problem – may report to "any other member state concerned" under Article 12. The "other member state" addressed is, however, not obliged to engage in any meaningful dialogue to resolve the problem. Instead, the WFD and some other EU water legislation encourage member states to refer all potential interpretative or implementation differences to the European Commission. Under a quasi "good offices" procedure member states may report – individually or jointly – their problems to the Commission. However, all what the Commission is obliged to do is to "respond" to such a submission within a timeframe of six months. This procedure has been rightly criticised as lacking any enforcement power (Keesen et al., 2008), with no reported instance of recourse to it as yet. Given the European Commission's well-known reluctance to engage in the bilateral disputes of EU member states, it is unlikely to fulfil the role of a meaningful dispute settlement mechanism.

Regardless of the above avenues the affected member state can also sue the non-compliant other member state directly before the European Court of Justice (TFEU Art. 259). This procedure however suffers from a series of structural shortcomings that render such avenue of enforcement almost completely ineffective. First of all, prior to referring the case to the Court, the applicant member state must submit the matter to the Commission for a pre-litigation evaluation. If the Commission fails to take over the case within three months, it is only then that the applicant member state may refer the matter to the Court. This implies however that the Commission is not convinced of the legal (or political) merit of the case, so it is likely to intervene in the court procedure against the applicant member states, reducing the chances of success dramatically. Finally, member states themselves are very reluctant to challenge each other directly under EU law: in the EU legal order launching direct legal action between member states is a truly exceptional step. Therefore, not only are such cases extremely rare (only four such judgements have been delivered since 1958), they are also regarded as politically unfriendly gestures and a legally risky enterprise (Baranyai, 2015a).

Finally, EU law effectively deprives member states from the option of judicial settlement under multilateral treaties to which the EU is party (e.g. the UNECE Water Convention or basin treaties to which the EU is party). While under most of these treaties parties may accept the ultimate jurisdiction of the International Court of Justice or an arbitral tribunal, these submissions are recognised under EU law only vis-à-vis third (i.e. non-EU) countries. The reason for this is the expansive jurisprudence by the European Court of Justice, aiming to safeguard its monopoly to interpret EU law. In a landmark decision concerning the settlement of a dispute between Ireland and the United Kingdom relating to the UN Convention on the Law of the Seas (Mox Plant case), the European Court of Justice established that EU member states cannot have recourse to the dispute settlement system of an international convention that forms part of the EU legal order. Recourse to an extra-EU settlement mechanism – goes the verdict – would "create a manifest risk that the jurisdictional order laid down by the Treaties and, consequently, the autonomy of the [EU] legal system may be adversely affected" (C-459/03).

The overall assessment of bilateral dispute settlement therefore is not promising at all: general EU law deprives member states from an important dispute settlement mechanism under international law and what it offers instead is a set of procedures almost completely left to the initiative and judgement of the European Commission.

Institutional framework

The European Union does not have a specific water agency, let alone any transboundary water organisation. The fact that the European Commission is in charge of both policy development and legal enforcement has a number of advantages and disadvantages for hydro-politics in Europe.

European water law has benefited enormously from the wealth of expertise, organisational capacity and funding available for the Commission. The various working bodies, in particular the meeting of European Water Directors provide an important platform for addressing new challenges, such as climate adaption.

Nevertheless, it must also be kept in mind that the European Commission tends to pursue its own political and policy objectives that may not necessarily reflect those of the member states. Very often political considerations that are outside the water policy box have direct influence on water policy decisions. Moreover, as noted above, the Commission is strongly disinclined to get engaged openly in the bilateral issues of member states, even in rather clear situations. This has significant implications for the future status of water allocation matters (a bilateral political hot potato par excellence) or non-judicial conflict resolution mechanisms under EU law, two critical hydro-political vulnerability gaps.

Evaluation

The above analysis shows that while the EU has one of the most extensive and sophisticated supranational water policy, its governance framework has certain structural deficits that may eventually give rise significant cooperation gridlocks on shared river basins.

First, even though the EU's overall water policy framework provides for the close cooperation of member states in the development of river basin management plans and flood risk management plans, the obligations are almost exclusively of procedural nature and non-enforceable. As a result, the record of actual cooperation across the EU shows a mixed picture. Second, EU water policy has a one-sided ecological approach that fails to properly address the quantitative implications of water use and its transboundary impacts. Consequently, water allocation issues are almost completely missing from EU water law and institutional practice. This may become a critical gap as the effects of climate change are primarily expressed in increased variations in river flow and flow allocation problems have the highest conflict potential of all water management issues. Moreover, the EU does not have legal or institutional mechanisms in place to manage increased hydro-climatic variability, despite the high priority climate change enjoys in European politics. Finally, bilateral dispute settlement mechanisms available for EU member states have serious structural shortcomings. These include: no readily-available mechanisms are in place to address and assist bilateral compliance issues, the general EU infringement procedure is not capable to handle bilateral disputes, direct action before the European Court of Justice is politically unrealistic and legally risky, finally, recourse to international treaty based forums is considered a violation of EU law. The lack of meaningful alternative avenues should suggest the greater involvement of the European Commission in transboundary water issues. The Commission has however traditionally proved complacent to get engaged in the bilateral disputes of member states. Short of meaningful alternatives, member states are left to their own devices to handle their differences over shared water resources that results in lengthy disputes with high social and environmental costs.

Policy recommendations

In order to ensure the long term stability of transboundary water relations in the European the following recommendations can be formulated:

- *Address hydro-political vulnerability in a comprehensive manner:* the European institutions and member states should address hydro-political vulnerability in a comprehensive manner. The EU's relatively strong global rating does not mean that there are no significant gaps in European water governance.

- *Address transboundary water quantity management and water allocation:* the constitutional limits to adopting water quantity management measures should not be used as a justification for inaction. Despite the popular perception, the Treaty on the Functioning of the European Union does delegate the EU powers to address transboundary water quantity management (allocation included), it simply makes the adoption of binding rules on the subject more difficult. In view of its clear competence to do so, the relevant players, including the European Commission should thoroughly explore existing and possible intra-EU tensions that may arise over water allocation issues in a transboundary manner.

- *Review dispute settlement and enforcement mechanisms in the EU:* the availability and effective use of mandatory dispute settlement mechanisms is a major guarantee of the stability of inter-jurisdictional relations. The EU should also make use of the existence of a strong supranational legal and institutional framework. Institutional options for bilateral dispute settlement should be investigated without prejudice to the judicial monopoly of the European Court of Justice. Existing examples within and outside the EU include mediation, fact finding commissions, compliance mechanism, mutual evaluation, etc.

- *Strengthen the effectiveness of the existing cooperation mechanisms:* the experience of the first two planning cycles of the Water Framework Directive leaves ample room for improvement. The measures to enhance cooperation may include the development of guidance materials or procedural recommendations on the structure of member state cooperation, greater supervision by the Commission, strengthening the role of basin commissions, etc.

- *Active engagement of the European Commission in transboundary water cooperation:* the Commission could play a more active role making use of the diversity of its powers and its multi-faceted relationship with member states.

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