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Antecedents and Dimensions of Supply Chain Robustness: A Systematic Literature Review

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Article information

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Structured Abstract:

Purpose – The purpose of this paper is to provide groundwork for an emerging theory of supply chain robustness – which has been conceptualized as a dimension of supply chain resilience – through reviewing and synthesizing related yet disconnected studies. The paper develops a formal definition of supply chain robustness to build a framework that captures the dimensions, antecedents and moderators of the construct as discussed in the literature.

Design/methodology/approach – The authors apply a systematic literature review approach. In order to reduce researcher bias, they involve a team of academics, librarians and managers.

Findings – The paper (1) provides a formal definition of supply chain robustness, (2) builds a theoretical framework of supply chain robustness that augments both causal and descriptive knowledge, (3) shows how findings in this review support practice and (4) reveals methodological insights on the use of journal rankings in reviews.

Research limitations/implications – At this stage, managers may benefit from seeing these relationships as clues derived from the literature. The paper is fundamentally a call for researchers to conduct quantitative testing of such relationships to derive more reliable understanding and practical applications.

Practical implications – Rather than presenting empirical findings, this paper reveals to managers that visibility, risk management orientation and reduced network complexity have been the main predictive antecedents of supply chain robustness (as discussed in the academic literature). This provides a potentially important signal as to where to invest resources.

Originality/value – The study is the first to develop a formal definition of supply chain robustness and to establish a comprehensive theoretical framework for understanding the construct.

Keywords: Supply Chain Robustness, Antecedents, Dimensions, Systematic Literature Review

Article Classification: Literature review

Introduction

After decades of relative stability, Christopher and Holweg (2011) observed the emergence of a new era of turbulence in supply chains. The literature provides two main strategies for the way that supply chains and their entities can cope with such changes (changes are understood as events that cause deviations from status quo or disturbances in one or more nodes): reactive or proactive. Each of these strategies has been shown to reduce vulnerability (Wieland and Wallenburg, 2012).

A reactive strategy implies that the supply chain adjusts ex-post to changes, and supply chains adopting this strategy are usually referred to as agile supply chains (Braunscheidel and Suresh, 2009; Hoek *et al.*, 2001). This corresponds primarily to being flexible (Christopher and Towill, 2001) and being able quickly to adjust tactics and operations (Gligor and Holcomb, 2012). Postponement is a commonly used measure to achieve supply chain agility, as it delays the point at which the final customization step takes place, thereby reducing the time to respond to demand changes by adapting the final product (Feitzinger and Lee, 1997).

In contrast to a reactive strategy, a proactive strategy to cope with change implies that the supply chain implements ex-ante measures to cope with turbulence, with no adaptation needed during times of change. Supply chains adopting this strategy are usually referred to as robust supply chains (Klibi *et al.*, 2010; Vlajic *et al.*, 2012), where robustness corresponds primarily with being physically sturdy (Christopher and Peck, 2004) and being able to retain the same stable situation as before changes occurred (Asbjørnslett and Rausand, 1999). Incorporating redundancy, e.g. in reserves or back-up options, is a commonly used measure to increase supply chain robustness that can reduce vulnerability to change (Azadegan *et al.*, 2013).

Supply chain resilience, a third term used in this context, corresponds to balancing both reactive and proactive strategies (Melnyk et al., 2014; Sáenz and Revilla, 2014). Christopher and Rutherford (2004, p. 24) state that a "resilient supply chain is certainly robust" and that a "resilient supply chain must also be adaptable," leading Wieland and Wallenburg (2013) to argue that agility and robustness are dimensions of resilience, a notion that will be followed within this paper.

To date, many scholars in logistics and supply chain management have sought to define robustness in ways that emphasize different properties of the construct. Some of these definitions are presented in Table 1.

Research in supply chain management often seeks to identify dimensions and antecedents of vital constructs to develop a formal definition of the field and further develop its theory. Dimensions are understood as those mutually exclusive and commonly exhaustive (MECE) features that a robust supply chain consists of, while antecedents are understood as variables which predict the construct (Morris and Feldman, 1996). Prior research has identified dimensions (Gligor *et al.*, 2013) and antecedents (Gligor and Holcomb, 2012) of supply chain agility. However, research has not yet sought to establish a comprehensive theoretical basis for understanding supply chain robustness, connecting the insights and information available in the literature. This is astonishing: arguably, prevention is better than cure – it is better to engage in loss avoidance and pre-emptive risk mitigation than deal with the consequences of actual disruptions (Kleindorfer and Saad, 2005). Lavastre *et al.* (2012) analyzed data collected from 142 general and supply chain managers and found that the majority prefer a robust supply chain strategy over an agile one, considering the latter "expensive and uncertain in its implementation" (ibid., p. 835). Wieland and Wallenburg (2012) analyzed data collected from 270 manufacturing managers to

Table 1 Definitions of supply chain robustness

Source	Definition
Meepetchdee and Shah (2007, p. 203)	"The extent to which the supply chain is able to carry out its functions despite some damage done to it."
Ferdows (1997, p. 86)	"A robust network is one that can cope with changes in the competitive environment without restoring to extreme measures."
Klibi *et al.* (2010, p. 290)	"A [supply chain network] design is robust, for the planning horizon considered, if it is capable of providing sustainable value creation under all plausible future scenarios"
Kouvelis *et al.* (2006, p. 452)	"The designed supply chain is robust in the sense that it hedges the firm's performance against the worst contingencies in terms of uncertain factors (…) over a planning horizon."
Vlajic *et al.* (2012, p. 177)	"We define supply chain robustness as the degree to which a supply chain shows an acceptable performance (…) during and after an unexpected event that caused disturbances in one or more logistics processes."
Wieland and Wallenburg (2012, p. 890)	"Robustness is a proactive strategy that can be defined as the ability of a supply chain to resist change without adapting its initial stable configuration."
Asbjørnslett and Rausand (1999, p. 220)	"We define robustness as 'a systems ability to resist an accidental event and return to do its intended mission and retain the same stable situation as it had before the accidental event'."

identify the effect of robustness and agility strategies on business performance. They found that robustness has a direct, strong positive effect on business performance, whereas only an indirect effect of agility could be shown. To date, research has identified different measures that lead to supply chain robustness (Nair and Vidal, 2011; Tang, 2006), but managers and academics still need to understand the theoretical basis of the construct. This research addresses this gap through developing a comprehensive framework that highlights the antecedents that enable the effective implementation of supply chain robustness measures.

The purpose of this paper is two-fold: First, to explore the multi-dimensional nature of supply chain robustness and thus to build a formal definition of it. Second, to identify antecedents of supply chain robustness and moderators of the antecedent-construct relationship.

The remainder of this paper is organized as follows: Section 2 outlines the research design and the efforts made to decrease bias; Section 3 puts forward a conceptual framework of supply chain robustness; and Section 4 discusses the scientific and managerial implications of the framework developed.

Research Design

This study applies a systematic review approach to identify dimensions, antecedents and moderators of supply chain robustness (cf. Tranfield *et al.*, 2003). In order to reduce bias during the research, the following steps were taken: The study (1) builds upon the feedback of a panel of experts, (2) embraces the expertise of librarians, (3) involves multiple researchers, (4) searches two databases and (5) avoids limiting itself to specific publications. The steps in this review process are outlined in detail below.

Locating Articles

A systematic literature search of databases should identify as complete a list as possible of pertinent literature while keeping the number of irrelevant hits low

(Duff, 1996). In order to limit bias, a panel of experts from Asia, Europe and North America contributed keywords and recommended relevant articles. The panel consisted of eight academics with long standing expertise in researching the area of supply chain risk management, and five supply chain managers from diverse industries with expertise in the field.

Two databases were selected for the literature search: Business Source Complete (via EBSCO) and SSCI-Database (via ISI Web-of-Knowledge). These databases were selected as they have some of the largest repositories of business research and are typically used in literature reviews (e.g. Carter and Easton, 2011; Hopp, 2004). With the assistance of two librarians specializing in business science and economics, the list of keywords provided by the panel was adjusted for keywords that were too broad or likely to identify literature related to other research areas.

In addition to the list of keywords, the experts provided eight articles (Chopra and Sodhi, 2004; Craighead et al., 2007; Klibi et al., 2010; Tang, 2006; Vlajic et al., 2012; Wagner and Bode, 2006; Wieland and Wallenburg, 2012; Zsidisin and Wagner, 2010) which were central to the research question. All eight articles are listed in EBSCO's Business Source Complete database (BSC). To categorize literature, EBSCO manually assigns subject headings (also called descriptors). Whereas authors can (mostly) choose any keyword for their articles, EBSCO assigns subject headings only from a controlled list. Through combining the subject headings for the eight articles and the list of keywords, the search string was constructed applying the usual block building approach (see Table 2). The first block of the dichotomous search string identifies articles discussing the construct of "robustness" or close synonyms. The second block confines the articles to those having the supply chain as their unit of analysis.

The ISI search engine does not provide subject headings but uses a keyword search. This requires a different approach since keywords, as opposed to subject terms, are a product of the authors of the individual articles. Whereas EBSCO's standardized subject headings made it easy to identify relevant literature, additional keywords were needed to capture the literature in ISI. The second block of the initial search string was hence extended with additional keywords provided by the experts. For the second section of the search string a Title Search was chosen, as a comparison of the results of Title Search and Topic Search suggested better results and less irrelevant literature for the former.

The electronic search process resulted in the identification of 1,244 articles from BSC and 238 articles from SSCI, 1,356 articles in total. In spite of the different search approaches, the searches provided a considerable overlap of the results – an indication for substantial consistency of the search strings. The unbalanced results are due to the different listings of literature and literature types in the databases, and the fact that BSC's repository is considerably bigger. The resulting records of citations and abstracts were exported and compiled using Citavi, a referencing database.

Table 2 Search strings for database search

EBSCO	*(robust* OR continuity OR vulnerability OR resilient OR perturbation* OR (risk driver*) OR mitigation) AND ((DE "SUPPLY chains") OR ("supply chain") OR (DE "SUPPLY chain management") OR (DE "SUPPLIERS") OR (DE "REVERSE logistics"))*
ISI	*(TS=(robust* OR continuity OR vulnerability OR resilient OR perturbation OR (risk driver*) OR mitigation) AND TI=((supply chain*) OR (supply network*) OR (logistical network) OR (demand chain) OR (supply management) OR SCM OR (production and inventory) OR (supply risk) OR (reverse logistics)))*
Notes:	DE: Descriptors; TI: Title Search; TS: Topic Search

Article selection and evaluation

Pawson (2006) encourages reviewers to include a wide range of studies, suggesting the value of a report for a research synthesis can only be determined while conducting the synthesis. This standpoint is ultimately supported by other researchers discussing journal rankings and their impact on the dispersion of SCM publications (McKinnon, 2013; Starbuck, 2005). After careful consideration, it was decided to apply no a priori restrictions to the database search. Following this decision, in the effort to follow the rigorous methodological approach proposed for a systematic literature review (e.g. Denyer and Tranfield, 2009; Tranfield *et al.*, 2003), the authors did not restrict their search to particular journals (Briner *et al.*, 2009). Consequently, the studies reviewed come from multiple research outlets. A related question, can additional relevant information be retrieved from publication outlets that have a low impact in the research community? is addressed at the end of this subsection.

Based on a list of inclusion criteria (see Table 3), which was built on discussions among the three authors, the summaries of all articles were independently checked in a blind procedure. Decisions were based on the content of the summaries, with any additional information hidden, and were inclusive, rather than exclusive. In order to check for inter-coder reliability, an initial sample of 50 summaries was reviewed for inclusion by two of the authors. Whenever there was disagreement, the issue was discussed with a third researcher involved. If the summaries were not sufficiently clear, the complete article was read. Only 2.0 percent of the summaries resulted in disagreement between the researchers. To make sure that agreement was not a product of chance, Cohen's kappa was calculated to be 0.96 (Cohen, 1960). This rate far exceeds the recommended minimum for "very high reliability" (Landis and Koch, 1977), indicating a reliable process of excluding and including articles for review. The aforementioned steps reduced the resultant number of full articles for analysis and synthesis to 94 (see Figure). In order to identify dimensions, antecedents and moderators, these remaining articles were studied in two rounds of reading.

Analysis and Synthesis of Articles

For the analysis, the 94 articles were randomly entered into a Microsoft Excel spreadsheet, paying no attention to their publication outlets. They were then analyzed for those features used when describing a robust supply chain (dimensions). A subsequent discussion among the authors found two distinct dimensions used to

Table 3 Inclusion criteria

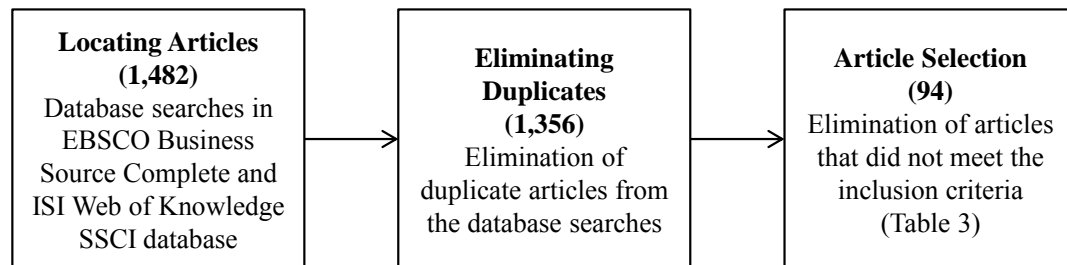| Inclusion Criteria	Rationale
Summary must demonstrate the supply chain as the clear focus/object of the research.	As this research is not restricted to any journals, research on other subjects than supply chains may occur.
A construct is mentioned that can be called "supply chain robustness," as it describes a supply chain's ability to maintain performance during times of change, through proactively implemented measures.	The focus of the research is to study supply chain robustness.
Summary must show clear indication of dimension and antecedents or moderators of supply chain robustness	The focus of the research is to study dimensions/antecedents and moderators of supply chain robustness.
Article must be written in English.	English is the dominating research language in the field of supply chain management.

describe robust supply chains: avoidance and resistance, described with various synonyms, e.g. "prevent" (Speier *et al.*, 2011) or "hedge" (Hofmann, 2011). Sixty-five studies were identified to use synonyms of resistance, and 61 to use synonyms of avoidance, showing a considerable overlap in the use of both dimensions. For this study, resistance is defined as the ability of a supply chain to withstand change (see Table 4). A common measure suggested to increase resistance to changes is the implementation of buffers into the network (e.g. Sawik, 2013; Schmitt, 2011). However, as not all changes can be resisted, some need to be avoided in order to stay robust. Avoidance, as the second dimension of supply chain robustness, refers to the ability of a supply chain not to be affected by change. This shows that during times of change, a robust supply chain is either capable of resisting such change, or takes measures to avoid it.

Building upon these two dimensions, a formal definition of supply chain robustness was formed, which provided the basis of the robustness framework: the ability of a supply chain to resist or avoid change. The new definition is plain and distinct from related constructs, an essential foundation for subsequently identifying antecedents.

In a second round of reading, variables were identified that were deemed either to predict the ability of a supply chain to resist or avoid change (antecedent) or may explain the variability in effect sizes of such variables on the construct (moderator). The spreadsheet was extended by an additional column each time a variable was identified that had not previously been identified. Altogether, 62 such variables were identified.[1]

The coded information was then synthesized in order to elevate the abstraction of the framework (Wacker, 1998). Studies that apply the same empirical data collection process on the same topic can usually be synthesized through a meta-analytic approach (Denyer and Tranfield, 2006). However, the reviewed literature is more heterogeneous, and therefore more amenable to an interpretative synthesis to "interpret research to build higher-order theoretical constructs" (for additional information see Rousseau *et al.*, 2008, p. 492). To reduce human subjectivity in this research step, the authors drew on aspects of the Q-methodology (cf. Ellingsen *et al.*, 2010), presenting two authors and an additional researcher with the 62 variables printed on small cards (Q-sample) instructing them independently to arrange the variables and put them into relation to one another to build higher-order antecedents and moderators. If a variable could not be synthesized with others due to its distinct structure and content, it was considered an antecedent in itself or, depending on the way it fit with the concept, a moderator.

Figure 1 Article selection process

| Locating Articles (1,482) Database searches in EBSCO Business Source Complete and ISI Web of Knowledge SSCI database | Eliminating Duplicates (1,356) Elimination of duplicate articles from the database searches | Article Selection (94) Elimination of articles that did not meet the inclusion criteria (Table 3) |

Table 4 Dimensions of supply chain robustness

Dimension	Definition
Resistance	Ability of a supply chain to withstand change.
Avoidance	Ability of a supply chain not to be affected by change.

[1] A table with all variables for each process step can be obtained from the authors.

After no further synthesis of the variables was possible, the respondents explained the placing of their cards (Q-sort) to each other. Similarities among the Q-sorts were then determined and consolidated, resulting in identifying 20 distinct antecedents including one moderator of supply chain robustness.

In a subsequent open discussion among the authors and two outsiders, an initial framework of supply chain robustness was built out of the consolidated set of variables. Antecedents that were mentioned in more than five different studies were automatically included in the framework; below this limit, the theoretical soundness of the antecedents was discussed in depth with close reference to the studies they were extracted from. Only if all researchers were convinced of its importance was the antecedent included in the framework. The completed framework consists of eight antecedents and one moderator.

In a further analysis to verify a posteriori whether outcomes would have been different by selecting journals according to impact factor (IF), the authors ranked the 94 articles according to the IF reported in Thomson Reuters' Journal Citation Report (2012). It was found that the proposed theoretical framework of supply chain robustness could have been developed by only resorting only to articles with an IF 1.3 or higher. That is, the remaining articles did not show any new or different insights to those revealed in the better ranked journals. Applying this restriction leaves 50 articles from 21 journals. This shows that research outcomes would not have been different had the choice been made to include only journals above the established threshold of IF. This finding supports the validity of reviews that solely build upon journals that are commonly recognized as primary outlets within the field of supply chain management research.

Review Results

Based on the aforementioned research steps, this study develops a theoretical framework of supply chain robustness. In particular, it explores the multi-dimensional nature of the robustness construct, its antecedents and moderators. It is not an original observation that researchers in supply chain management usually see the dyad or the triad as the smallest unit of analysis in a network (Choi and Wu, 2009). The reviewed articles partially reflect this, as one group of articles studies two (e.g. Baghalian et al., 2013; Rothenberg and Ettlie, 2011) or multiple echelons of the supply chain (e.g., Klibi et al., 2010; Meepetchdee and Shah, 2007). However, there is a second group of articles that emphasizes the importance of firm internal processes for the supply chain (e.g. Hazra and Mahadevan, 2009; Vlajic et al., 2012). The theoretical framework developed accounts for these different perspectives and shows that in order to achieve a robust supply chain, robustness needs to be achieved on both inter- and intra-organizational levels. For both levels, distinct antecedents were identified. Each level is interdependent in such ways that the achieved level of robustness of a single node usually impacts the robustness of the network. For example, when a firm makes a sourcing decision that aims to increase intra-organizational robustness, managers must consider the impact of this decision on inter-organizational robustness. For instance, the robustness of a firm can also be increased through the proper selection of supply chain partners (Sawik, 2013; Tomlin, 2006). A similar phenomenon can be experienced for outsourcing decisions. Outsourcing adds complexity to supply chains, since it impacts their design, but also has positive effects on robustness as it allows a firm to focus on its core activities (Hsiao et al., 2010; Williamson, 2008). The results of the literature review are outlined below.

The framework developed consists of five parts. As Figure 2 shows, robustness on both inter- and intra-organizational levels consists of the dimensions resistance and avoidance. Figure 2 also illustrates the identified antecedents and the moderator.

Intra-Organizational Robustness and its Antecedents

Leadership Commitment

Leadership commitment to strategic initiatives is the foundation for the effective implementation of common goals within an organization (Speier *et al.*, 2011). Decision makers have a crucial role as they inspire as well as motivate employees (Grötsch *et al.*, 2013). Their cognitive style impacts the organization's attitude towards anticipation, pro-activeness and, in turn, pursuit of robustness actions (Grötsch *et al.*, 2013; Speier *et al.*, 2011). They prioritize and help to ensure that resources are being employed in a more focused way (Hall *et al.*, 2012). Supply chain managers can make the implications of strategic decisions more transparent for the board and can prioritize on identifying and avoiding emerging problems (Peck, 2005). This suggests that leadership commitment to robustness plays an important role in enforcing planning efforts to build intra-organizational robustness. Leaders' actions, what they do or fail to do, can change the robustness of a firm.

Proposition 1: Organizations that have leadership commitment to robustness will experience an enhanced intra-organizational robustness.

Human Capital

Employees have a critical role to play, as the interface between strategy set at the top and operational execution. Their skillset is a valuable resource for implementing new initiatives within an organization (Figueira *et al.*, 2012; Vlajic *et al.*, 2012). As pointed out by Blackhurst *et al.* (2011, p. 380), if employees are well educated and properly trained, they are equipped with the "necessary skills to know when it is appropriate to take action," when it is reasonable to stock inventory, or whom to communicate with. Employees of an organization know how to properly apply IT systems (Hall *et al.*, 2012) and, as argued by Dynes *et al.* (2007), can also help to build resistance to disruptions of the IT system. As delivering order quantities or continuous production of products can commence only if standardized routines are being followed, supply managers are argued to be the key knowledge source for identifying potential supply problems and knowing the appropriate steps to take in order to enhance robustness (Zsidisin and Wagner, 2010). It is therefore argued that the human capital of an organization is a valuable resource, necessary to achieve intra-organizational robustness.

Proposition 2: Within an organization, well-educated and skilled human capital has a positive influence on intra-organizational robustness.

Intra-organizational Relationship Magnitude

The magnitude of interaction and exchange of information between different intra-organizational entities is central for enabling intra-organizational robustness. Strategic and operational sharing of information and knowledge on product design, production processes, logistics and quality, as well as supply and demand status, are argued to enable better intra-organizational coordination and management (Hall *et al.*, 2012). Collaborative meetings can help to exchange timely and relevant information among departments (cf. Lavastre *et al.*, 2012). Increased collaboration between the engineering and purchasing departments could, for example, help to redesign products in such ways that necessary resources are more readily available in the market. Vlajic *et al.* (2012) advise managers that a closer cooperation between people who are doing planning and those who execute plans is helpful for enhanced strategic planning. From an

Figure 2 A conceptual framework of supply chain robustness
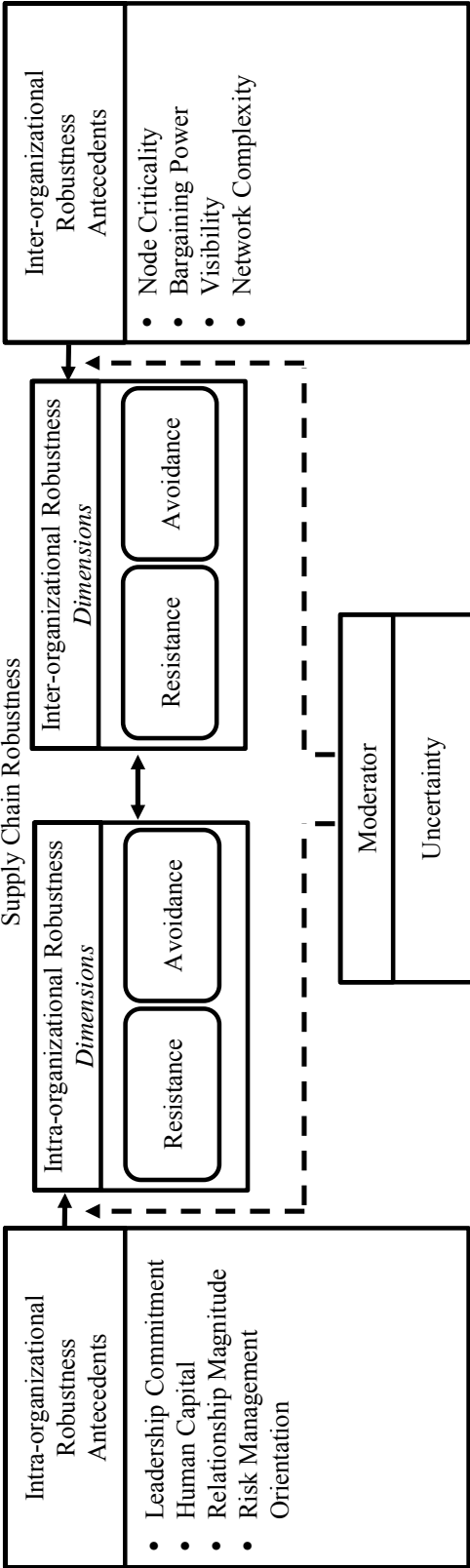
internal perspective, it is suggested that communication between multiple people and functions within an organization increases awareness (Norrman and Jansson, 2004) and decreases process variability (Chen *et al.*, 2013). An enhanced intra-organizational relationship is therefore argued to foster the robustness of a firm.

Proposition 3: The degree of an enhanced inter-departmental relationship within an organization of a supply chain is positively related with intra-organizational robustness.

Risk Management Orientation

As suggested earlier, risk management at every node of a supply chain can help to prevent cascade failure of the supply chain (Wieland and Wallenburg, 2012). Risk management orientation is argued to be necessary on multiple levels (Jüttner and Maklan, 2011): tangible (e.g. product design), organizational (e.g. make-or-buy) and intangible (e.g. reputation).On an intra-organizational level it is understood as a culture that helps to facilitate the implementation of proactive risk measures and that fosters learning from previous events (Lin and Wang, 2011; Schmitt, 2011). Zsidisin and Wagner (2010) find that understanding a firm's propensity to risk helps to better implement measures to hedge for disruptions. An increased risk management orientation is hence suggested to foster intra-organizational robustness.

Proposition 4: An increased risk management orientation within an organization has a positive impact on intra-organizational robustness.

Inter-Organizational Robustness and its Antecedents

Node Criticality

A number of researchers identified a first antecedent of inter-organizational robustness in their discussion on the criticality of individual nodes in supply chains (e.g. Bhattacharya *et al.*, 2013; Craighead *et al.*, 2007). Even though each node within a network (should) play a value-adding role, some nodes are typically more critical than others. The measure of node criticality is relative to other nodes within a supply chain. Nodes that are considered critical are, for example, organizations that have multiple suppliers or sell to relatively many customers. Reiner and Trcka (2004) show in their research the inherent criticality of distribution centers, as they have a crucial function in coping with demand changes. Joint measures, such as strategically storing inventory at critical nodes, can help to resist disruptions (Tang, 2006). This could be achieved through setting appropriate contracts among supply chain partners (Hazra and Mahadevan, 2009). It can be conjectured that changes that negatively impact critical nodes have an increased negative impact on the supply chain. It is hence suggested that increased criticality of a single supply chain node is negatively related to supply chain robustness.

Proposition 5: The greater the relative criticality of individual nodes of a supply chain, the lower will be the level of achieved inter-organizational robustness.

Bargaining Power

Bargaining power of a single node within a supply chain is identified as a second antecedent of inter-organizational robustness. Nodes with high bargaining power within a supply chain are, for example, single suppliers of a product or buyers of products that are readily available in the market (a situation often experienced in the automotive industry, cf. Thun *et al.*, 2011). Organizations that experience increased bargaining power in comparison with their supply chain partners can take advantage of this opportunity and, for example, favor one customer over another (Abercrombie,

2007; Sawik, 2013). Increased bargaining power is thus argued to raise the probability of opportunistic behavior among supply chain members – behavior that is detrimental to the network's capability to cope with changes (Jüttner and Maklan, 2011).

However, bargaining power can also function as an enhancer of inter-organizational robustness. As noted by Williamson (2008), taking advantage of one's own bargaining power is a m yopic and sometimes inefficient behavior. If a node experiences increased bargaining power, it has the opportunity to play a vital role in increasing the robustness of the entire network. The node then forms a "benevolent dictator", an approach that is based not on good will (Hofmann, 2011), but aims to decrease the vulnerability of supply chain partners for the good of the "dictator" organization. It is therefore argued that the relative bargaining power of a firm can have a two-sided impact on inter-organizational robustness.

Proposition 6a: Supply chains with increased relative bargaining power of s ingle nodes can be detrimental for inter-organizational robustness if the powerful node is not willing to support its supply chain partners.

Proposition 6b: Supply chains with increased relative bargaining power of s ingle nodes enable an increased inter-organizational robustness if the powerful node sees the long-term benefit of its activity and is thus willing to support its supply chain partners.

Visibility

Christopher and Lee (2004) suggest that a key element in any strategy to mitigate supply chain risks is improved visibility. The reviewed research that discusses visibility does this from either a relational or network structure perspective.

Relational aspects among supply chain members and their resulting impacts are subject of discussion in multiple studies (e.g., Lavastre *et al.*, 2012; Whipple and Roh, 2010). Lavastre *et al.* (2012) suggest that efforts to im prove supply chain visibility through the sharing of risk-related information leads to increased supply chain risk avoidance, thus a compatible IT infrastructure can function as a key facilitator for information exchange among partners (Hall *et al.*, 2012; Speier *et al.*, 2011). The reviewed literature also makes clear that information exchange at the lower echelons of relationships most effectively enables inter-organizational robustness. Wieland and Wallenburg (2013) empirically demonstrate that both communicative and cooperative relationships have positive influences on supply chain robustness.

Regional, and thus dense, supply chains are also argue d to enhance network visibility (Shao, 2013; Wagner and Bode, 2006). Some of the motivation for organizations within a supply chain to locate in close proximity lies in the potential to gain access and share knowledge (Deane *et al., 2009)*. The network structure can thus be argued to enhance the visibility of a supply chain. However, a disruption affecting a dense part of a network could be quite severe as multiple of the members can be affected (Craighead *et al.*, 2007). The greater the geographical dispersion, the less it is like ly that in case of changes close to a supply chain member the entire network will be a ffected. Thus, managers have to balance risks and enhanced communication when designing their supply chain. Nevertheless, it is suggested that inter-organizational robustness seems to be enhanced through increased visibility in the network.

Proposition 7: Supply chain visibility is positively related to supply chain robustness.

Network Complexity

Increasing network complexity requires firms to invest more heavily in measures to mitigate supply chain risk (Craighead *et al.*, 2007; Speier *et al.*, 2011).

Network complexity is th ereby understood as the degree of connectivity within the network (Meepetchdee and Shah, 2007). Two related factors have been discussed as contributing to increased network complexity and hence to decreased robustness: (1) number of nodes (Blackhurst *et al.*, 2011) and (2) network length (Nair and Vidal, 2011). As the number of nodes in a supply chain increases, the supply chain becomes longer and more complex. A complex supply chain potentially implies that more efforts and resources are needed to synchronize and coordinate activities within the network to describe the state of the system (Meepetchdee and Shah, 2007). If these efforts fail, unexpected changes in a supply chain that occur (or originate) at a single node can potentially propagate through the supply chain and cause harm to its members. It is therefore argued that increased network complexity is likely to be detrimental to increased inter-organizational robustness.

Proposition 8: Reduced network complexity of supply chains (i.e., reduced number of nodes and network length) is positively related with a higher inter-organizational robustness.

The Moderating Role of Uncertainty

A key characteristic of the supply chain robustness literature is the researchers' emphasis on uncertainty within and outside of the supply chain. Several scholars have ar gued that the level of uncertainty may form an important boundary condition for strategies in supply chains (e.g., Chopra *et al.*, 2007; Klibi *et al.*, 2010). Research that includes references to uncertainty can be clustered into two fields: studies researching how uncertainty impacts (a) the network or (b) firm decisions. Uncertainty usually occurs when information on the environment is incomplete or even non-existent. Klibi and Martel (2012, p. 645) define it as "the inability to determine the true state of the future business environment which may be partially known or completely unknown." That is, a b usiness environment is certain under perfect information and uncertain under partial information. However, uncertainty, though a precondition for risk to occur, need not necessarily lead to a risky situation (Leat and Revoredo-Giha, 2013).

Moderation of antecedents–intra-organizational robustness: Certainty concerning environmental factors on an intra-organizational level is needed to detect potential changes and to subsequently disseminate pertinent information to relevant entities within the organization (Azadegan *et al.*, 2013). Managers need to reduce uncertainty to reduce risks and allocate resources to manage such risks (Lavastre *et al.*, 2012), but the more unpredictable the system, the harder it is for an organization to take effective measures to achieve intra-organizational robustness. In the reviewed literature, several analytical methods and mathematical programming tools have been proposed to hel p identifying potential changes in an uncertain environment (cf. Fernández *et al.*, 2012; Van Landeghem and Vanmaele, 2002).

Van Landeghem and V anmaele (2002) identified in the literature different sources of unce rtainty that have medium or high leverage on strategic decision making: stochastic costs, political environment, customs regulations and stochastic demand. Hazra and Mahadevan (2009), in their procurement model, use capacity reservation in the presence of demand uncertainty, while Chopra *et al.* (2007) and Tomlin (2006) mathematically show that t he sourcing strategy of a firm should be different depending on the degree and type of uncertainty the firm is exposed to. Although these authors were not explicitly testing for leadership commitment, human capital, communicative relationship and risk management, the studies indicate a decreased robustness effect of intra-organizational antecedents under increased uncertainty.

Moderation of antecedents–inter-organizational robustness: Several studies discuss robust supply chain network design problems under uncertainty (e.g., Baghalian *et al.*, 2013; Klibi *et al.*, 2010; Lin and Wang, 2011), with Azadegan *et al.* (2013) researching the impact of operational slack on environmental uncertainty. Uncertainty on a network level is thereby defined through instability, turbulence, environmental complexity and scarcity of re sources. Despite these articles, very few studies have formally considered uncertainty's influence on no de importance, bargaining power and ne twork complexity, although exceptions include Shao (2013) and Deane *et al.* (2009), who found that dense node clusters become more prone to uncertainty affecting multiple nodes of the system than a more dispersed network.

The following section discusses the scientific and managerial implications of the framework developed.

Implications

The identified framework helps managers and researchers alike to consider the impact of various intra- and inter-organizational variables on the focal construct. It provides value to managers through deriving nine propositions relating supply chain robustness to eight antecedents. The antecedents offer enhanced guidance to help a firm systematically assess the extent to which it is capable of increasing the robustness of its supply chain particularly in the instance of scarce resources.

The relationships within this framework are derived from the literature. Deciding the degree to which the findings presented in this review can inform practice is a matter of judgment for the practitioner. Three of the antecedents have been researched in 49 percent of the reviewed studies (visibility, risk management orientation, network complexity) and are, therefore, considered to have a relatively strong impact on supply chain robustness. Others, however, are less reliable, as they occur less frequently, thus posing potential future research opportunities.

The set of antecedents show managers the settings that will enable the proper implementation of supply chain robustness measures. In particular, managers should foster supply chain visibility in order to be able to map their supply chain and identify changes ahead of time to be able to implement proactive avoidance or resistance measures (cf. Sáenz and Revilla, 2014). Building supply chain visibility is a non-trivial matter. Visibility can be increased through enhanced relationships or through redesigning the network.

The study findings also reveal that firms should show an adequate risk management orientation. When Ericsson changed its r isk management approach, it decided to create a corporate risk ma nagement function that cooperates and works with other functions and business units in a matrix-oriented way (Norrman and Jansson, 2004). Ericsson emphasized the importance of risk management in its organization and clearly defined responsibilities to better enable a proactive risk management approach. They also showed that such a redesign of organizational principles and responsibilities can be supported by a ri sk management council of business functions which seeks to increase intra-organizational information exchange – a vital aspect of the supply chain robustness antecedent of intra-organizational relationship magnitude.

Further, global sourcing has been argued to contribute to the structural complexity of the supply chain (Hendricks and Singhal, 2005). The robustness framework suggests a negative impact of network complexity on supply chain robustness. The authors therefore encourage managers to adopt thinking in total costs when assessing their supply chain structure (cf. Chopra and Sodhi, 2014). That is, some drivers for

sourcing abroad, such as cheap labor and products may sometimes prove disadvantageous if non-direct cost elements for sourcing globally, such as increased exposure to risks, are allowed for as well.

Through the study findings, managers are also encouraged to identify critical nodes through analyzing informational and physical flows in their supply chain. The identification of critical nodes is a prerequisite for the efficient and effective implementation of supply chain robustness measures.

It is further suggested that managers need to be aware of the power position their firm takes up in their supply chain. This research suggests that supportive actions towards supply chain partners may, in the long run, pay off for powerful companies through increased supply chain robustness.

Managers are also encouraged to foster well-educated and skilled personnel as well as leaders who are committed to robustness. Cappelli (2008) suggests that managers follow four principles to ensure an effective talent management: Using internal development programs, implementing modularized training systems, developing novel cost-sharing programs, and generating firm internal incentives to retain personnel.

Final remarks

Several researchers have suggested supporting ideas and concepts of supply chain robustness. However, there is still a huge gap when it comes to understanding the dimensions, antecedents, and moderators of the construct in producing a theoretical basis of supply chain robustness.

The theoretical framework identified in this research fills this gap. It provides groundwork for an emerging theory of supply chain robustness through synthesizing many hitherto disconnected studies published in multiple research outlets. The framework seeks to explain how and why variables are related and makes specific predictions of such relationships. To increase the soundness of the framework, the authors involved academicians, practitioners and librarians to identify, analyze and synthesize the 94 articles.

This study complements prior research on dimensions and antecedents of supply chain agility (Gligor and Holcomb, 2012; Gligor *et al.*, 2013), with the provision of two dimensions and eight antecedents of supply chain robustness. It is a vital building block for better understanding the foundation of the two fundamental reactive and proactive supply chain strategies (Wieland and Wallenburg, 2013).

This paper also presents a call for researchers to conduct rigorous quantitative testing of the framework to derive reliable practical implications. The focus of such research should be to test the existence of and identify differences in the strength of the relationships. More empirical research is also encouraged on the moderator of the framework to further deepen the understanding of the extent to which this variable affects the effect size of each antecedent.

Besides the theoretical and practical findings of this study, it also reveals some interesting methodological insights for literature reviews in supply chain management. In the effort to follow the rigorous methodological approach proposed for a systematic literature review (Pawson, 2006; Tranfield *et al.*, 2003), the authors did not restrict their search to particular journals. Consequently, the reviewed articles came from multiple research outlets. During the analysis it was found that the theoretical framework of supply chain robustness can be developed using only journals with an IF of 1.3 or higher; the other articles did not show any new or different insights than those in the

more highly-ranked journals. Hence, the r esulting framework is s olely built upon journals that are considered primary outlets within the field of supply chain management (see list of References).

A cautious methodological conclusion at this point would be that literature reviews that restrict their database searches to specialized journals listed in the upper echelon of journal rankings do not necessarily miss out on basic research contributions. Despite this interesting methodological finding, it needs to be emphasized that one should not jump to conclusions about the usefulness of doing a literature review using journal rankings versus using a broad literature review approach. These results ought to be treated as tentative until more specific research is conducted on the need to include a broad range of publications.

The paper's findings are limited by the method applied. In c onducting research, the reviewed articles commonly focus on goods, although no restriction was made on this. Therefore, successful application of the framework to service supply chains remains uncertain. The findings could possibly be flawed if published research does not reflect what is identified, reflecting a bias regarding only publishing research that is interesting enough, i.e. publication bias (Rosenthal, 1979). The authors believe that this study can be considered to be representative, supported by the fact that the analysis made a posteriori about the IF of the selected journals has revealed that the list used in this research included the most prestigious research outlets, suggesting that most relevant and high quality research has been taken into account. This is supported by other literature reviews made in prestigious journals (e.g., Leuschner, *et al.*, 2013; Machuca *et al.*, 2007).

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