

Causes and Effects of Supply Chain Disruptions

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List of Abbreviations

3PL	Third-party logistics (service) provider
AEO	Authorized economic operators
ANOVA	Analysis of variance
ART	Alternative risk transfer
AVE	Average variance extracted
BP	Breusch-Pagan
CFA	Confirmatory factor analysis
CFI	Comparative fit index
CFO	Chief financial officer
COO	Chief operating officer
C-TRAT	Customs-trade partnership against terrorism
df	Degrees of freedom
EM	Expectation-maximization
EQS	Equations (Structural equation modeling software by Multivariate Software, Inc.)
ERP	Enterprise resource planning
GFI	Goodness of fit index
GQ	Goldfeld-Quandt
H	Hypothesis
HRT	High reliability theory
IR	Indicator reliability
IT	Information technology
M	Mean (\bar{x})
MANOVA	Multivariate analysis of variance
MAR	Missing at random
ML	Maximum likelihood
MTF	Make-to-forecast
MTO	Make-to-order
NAT	Normal accident theory
NNFI	Non-normed fit index (also TLI)
OEM	Original equipment manufacturer
OLS	Ordinary least squares
Q-Q	Quantile-quantile
RBV	Resource-based view
RMSEA	Root mean square error of approximation
ROA	Return on assets
SARS	Severe acute respiratory syndrome
SB	Satorra-Bentler
SD	Standard deviation (s_x)
SE	Standard error

SEM	Structural equation modeling
SIC	Standard industrial classification
SRMR	Standardized root mean square residual
TAPA	Technology asset protection association
TLI	Tucker-Lewis index (also NNFI)
UK	United Kingdom
US	United States (of America)
USA	United States of America
VIF	Variance inflation factor

Cues to abbreviations of items and constructs are provided in Appendix 1.

Chapter 1 Introduction and overview of the research

1 Introduction

Supply chains are inherently susceptible to risky events. In the 1980s, Kraljic (1983) and Treleven and Schweikhart (1988) alluded to the specific risks arising from the inter-connected flows of material, information, and funds in inter-firm networks. However, it was not until recently that the interest in this phenomenon, both from scholars and practitioners, has grown. A large body of literature published in the past few years has depicted examples and case studies of events that disrupted supply chains and of the serious impact on the stricken firms (e.g., Sheffi, 2005). Supply chain disruptions can result in severe losses in shareholder value, sales, production, and reputation; they can also damage relationships with customers and suppliers. These reports are complemented by numerous publications proposing best practices, guidelines, and concepts for risk management strategies that aim for creating robust or resilient supply chains. What has actually fueled this new interest in supply chain risks and their proper management? This dissertation will argue that there are two major factors.

First, there are clear indications that the frequency, intensity, and diversity of types of adverse events with which firms have to cope are increasing on a global scale (Coleman, 2006; Helferich and Cook, 2002). Munich Re (2007), for example, stated in its annual report on natural hazards that “since 1950, there has been a long-term upward trend in the number of events and the amount of economic and insured losses” (p. 46). Likewise, Elkins, Handfield, Blackhurst, and Craighead (2005) observed that there had been an increase, both in the potential for and magnitude of supply chain disruptions. The crises and catastrophes that have occurred in the past

ten years underscore this development. Natural disasters such as Hurricane Katrina devastating the Gulf Coast of the USA in 2005 (Katz, 2005), terrorist acts such as the attack on the World Trade Center on September 11, 2001 (Sheffi, 2001), and epidemics like SARS in South-East Asia in 2003 (Swaminathan, 2003) are violent reminders that firms operate in a highly uncertain and turbulent world.

Second, the susceptibility of modern supply chains to the impact of such adverse events seems to have increased. Over the last 15 years, almost all industries have witnessed a remarkable change in their business environment, due to increased competition and the globalization of markets (D'Aveni and Gunther, 1995). At the level of the individual firm, this has resulted in a massive pressure to make intra-firm business processes and inter-firm supply chains either more efficient or more responsive and agile. In an attempt to meet this challenge and to adapt to the changed business environment, many firms decided to outsource or offshore large portions of their manufacturing activities, to source in low-cost countries, to reduce inventories and slack in their intra-firm processes, to streamline their supply base, or to collaborate more intensively with their supply chain partners (Christopher and Peck, 2004; Fisher, 1997; Hult, Ketchen, and Slater, 2004; Lee, 2002; Lee, 2004; Yoshino and Rangan, 1995). This arsenal of initiatives and strategies has been developed and supported by scholars in supply chain and operations management who have focused on supply chain performance in terms of gains in efficiency or responsiveness and agility (Kleindorfer and Saad, 2005; Lee, 2004). Certainly, many of the modern supply chain management initiatives, when properly used, can make operations either more efficient or more responsive and agile in stable environments – however, this might not hold true in more dynamic or turbulent ones (Zsidisin, Ragatz, and Melnyk, 2005b).

Therefore, academics now advise caution, arguing that many of these initiatives have not only created more complex supply chains, but also a higher degree of dependence between supply chain entities, which ultimately has increased the vulnerability of supply chains to unforeseen disruptions that can occur anywhere

in the supply chain (e.g., Gilbert and Gips, 2000; Harland, Brenchley, and Walker, 2003; Kleindorfer and van Wassenhove, 2004; Sarathy, 2006). Research in the field of organizational science has supported this reasoning, finding that due to their complex, tightly coupled, and technology-oriented processes, firms are becoming more prone to accidents and disruptions (Grabowski and Roberts, 1997; Lin, Zhao, Ismail, and Carley, 2006; Roberts and Libuser, 1993). It has been argued that in complex and turbulent business environments, unexpected events and adverse “surprises” would become the norm rather than the exception (Ansoff, 1975; Perrow, 1984).

In summary, (1) the current business environment is characterized by discontinuity, high velocity of change, and permanent risk for unexpected adverse events, and (2) many modern supply chains have become relatively sensitive to exogenous shocks. Hamel and Välikangas (2003) conjectured that “the world is becoming turbulent faster than organizations are becoming resilient” (p. 52). Consequently, many scholars have urged companies to tackle supply chain risks just as vigorously as they tackle financial and other business risks and to rethink their supply chain strategy and design (Christopher and Lee, 2004; Elkins et al., 2005; Tomlin, 2006).

Nevertheless, recent studies have identified a lack in the diffusion and implementation of supply chain risk management ideas in practice, and have found that many supply chain decision makers had been caught off-guard by the intensity of the disasters mentioned above (Jüttner, 2005; Mitroff and Alpaslan, 2003; Zsidisin, Panelli, and Upton, 2000). Accordingly, 38% of 247 recently surveyed CFOs said that their corporations were “sitting on too much unmanaged supplier risk” (Katz, 2004, p. 1).

From a research perspective, it is surprising that, although risks inherent in supply chains, their impact, and their appropriate management have been receiving significant attention, the current knowledge is still quite limited. The reason is that the vast majority of the information is anecdotal, case study-based, or normative.

Despite the usefulness of the extant body of research, there is little theoretical support to explain the causes and effects of supply chain disruptions. Very few studies have used theory-driven, confirmatory research approaches to examine supply chain disruptions. In contrast, much of the literature consists of rhetorical suggestions concerning risk management practices that lack both a theoretical background and a quantitative foundation. Likewise, findings from large-scale empirical research are scarce and mainly descriptive (Jüttner, 2005; Peck and Jüttner, 2002; Zsidisin and Ellram, 2003). Moreover, the literature on supply chain risk is limited, in part because there is no common and consistent nomenclature. A sound “vocabulary” of relevant terms would compensate for some of the limitations of the current literature.

This dissertation takes these issues into consideration and discusses the causes and effects of supply chain disruptions from several angles. The purpose of this dissertation is to advance the understanding of supply chain disruptions.

The remainder of this dissertation is structured as follows. In the subsequent sections of this chapter, the literature on supply chain disruptions and on supply chain risk is examined. Then, the three core research questions of this dissertation are outlined. Moreover, the research design and methodology used to investigate the delineated research questions are presented. Chapter 2 investigates the relationship between supply chain vulnerability and supply chain risk (Research Question I). Chapter 3 sheds light on the relationship between supply chain risk and performance (Research Question II). Chapter 4 focuses on the organizational responses to supply chain disruptions (Research Question III). Finally, Chapter 5 brings together the results of the previous chapters, summarizes the research results, and puts special emphasis on key academic and practical findings.

2 Literature review and development of a nomenclature

Several recent publications have attempted to advance the conceptual clarity of the terms used in the domain of supply chain risk management (e.g., Craighead, Blackhurst, Rungtusanatham, and Handfield, 2007; Harland et al., 2003; Jüttner, 2005; Ritchie and Brindley, 2007; Zsidisin, 2003). As mentioned earlier, despite these efforts, there is still no commonly agreed upon “vocabulary.” As a consistent use of terms is essential for any further investigation, the purpose of this section is to present a nomenclature, and to pinpoint and define the terms which constitute the conceptual foundation for this dissertation.

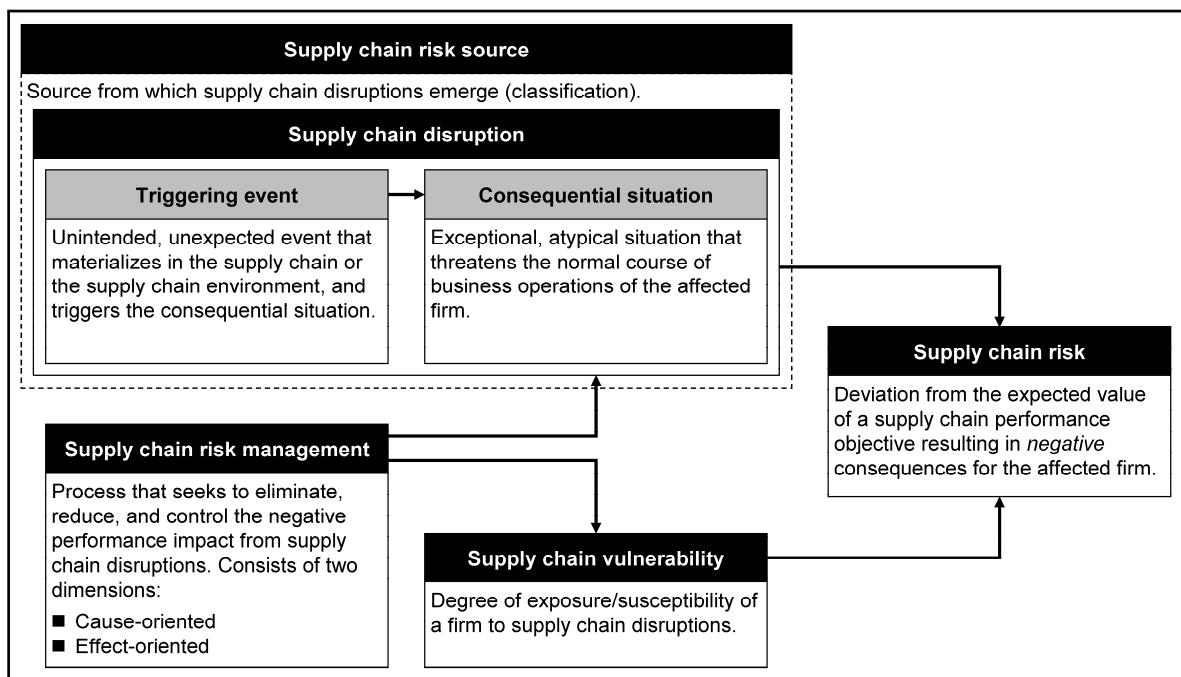


Figure 1: Nomenclature and definition of terms

In essence, the phenomenon under investigation in this dissertation is the negative outcome resulting from adverse events that occur in the supply chain. Four interrelated terms relate to this phenomenon: supply chain risk, supply chain disruption, supply chain risk source, and supply chain vulnerability. Figure 1 depicts this nomenclature and shows how these terms can be connected. In the

following sections, these terms will be derived from the pertinent literature, discussed, and defined.

2.1 Supply chain risk

Supply chain risk is the predominant theme in the literature on supply chain disruptions and is often applied as a catchall concept for a wide range of events, situations, potential threats, or uncertainties.

Risk in general is an elusive construct that has a variety of meanings, measurements, and interpretations depending on the field of research (Baird and Thomas, 1990; Jemison, 1987; Yates and Stone, 1992). There is a vast body of literature concerning risk in such fields as decision theory (e.g., Arrow, 1965), finance (e.g., Altman, 1968), marketing (e.g., Cox, 1967), management (e.g., March and Shapira, 1987), and psychology (e.g., Kahneman and Tversky, 1979). In this literature, there are two major perceptions of risk: (1) risk as *both* danger and opportunity and (2) risk as purely danger (Mitchell, 1995).

First, according to classical decision theory and according to portfolio theory in the field of finance, risk is conceived as the fluctuations (variability) around the expected value (mean) of a measure (Arrow, 1965; Pratt, 1964; Sharpe, 1964). In other words, risk is equated with variance and therefore has both a *downside* (loss) and an *upside* (gain) potential. This mean-variance approach, because of its objectivity, can be considered as the *Homo oeconomicus*' stance on risk.

In contrast, most dictionaries describe risk as the threat of injury, damage, or loss (e.g., McKechnie, 1983). The notion that risk has primarily negative consequences seems more consistent with the human perception than with the mean-variance approach. Several studies that have empirically investigated the risk perception and propensity of individuals, have found support for this. March and Shapira (1987), for example, examined the ways in which managers perceive and react to risk, and concluded that the majority tends to exaggerate the *downside*

potential of risk. Likewise, MacCrimmon and Wehrung (1986) found empirical support that managers do not consider variance to be risk but that they are rather concerned about the chances of losses.

Against the background of these two general views on risk, several publications have tried to define the term supply chain risk. Both of these views have been discussed and applied. For example, Jüttner, Peck, and Christopher (2003) followed the mean-variance notion and defined supply chain risk as a “variation in the distribution of possible supply chain outcomes, their likelihood, and their subjective value” (p. 200). In contrast, Harland, Brenchley and Walker (2003), after discussing various possible definitions, concluded that supply chain risk is primarily associated with the “chance of danger, damage, loss, injury or any other undesired consequences” (p. 52).

Based on interviews with scholars and managers in supply chain management, this dissertation adopts the latter notion of risk as purely negative. Considering the impact of recent disruptions on supply chains, this view corresponds best to the business reality of decision makers in supply chain management. Usually, managers consider their goals, such as a certain turnover or production volume, not so much as a target *point* but as lower limits of half-open ranges, e.g., to achieve *at least* a certain turnover or to spend *less* than a certain amount of resources (budget). Hence, a goal deviation only occurs when the defined thresholds are either not met or exceeded. In the insurance literature, such a situation is called *loss* or *damage* (Knight, 1921). For this reason, this dissertation will consider neither “happy disasters,” nor situations in which decision makers intentionally “gamble” on risk. *Risk* is conceived as *the deviation from the expected value of a (or more) performance measure(s), resulting in negative consequences for the focal firm*. Supply chain risk is equated with the detrimental consequences (i.e., negative performance impact) arising from a supply chain disruption (see next section). These consequences can be either direct or indirect (i.e., consequential loss), and can affect either major performance objectives (e.g., profit, company

value, or company continuity) or minor performance objectives (e.g., reputation or customer satisfaction) (Bode, Friederichs-Schmidt, Lindemann, and Sauer, 2007).

2.2 Supply chain disruptions

The terms *supply chain disruption* and *supply chain risk* are often used interchangeably. When surveying the relevant literature, one will find that despite increased scholarly effort to advance the conceptual clarity in this field, a *supply chain disruption* remains a vaguely defined and inconsistently used concept. Other terms that often are used in this context are *accident*, *error*, *disturbance*, *glitch*, *hazard*, *jolt*, *operational failure*, *operations crisis*, and *shock*. Table 1 shows some of these terms and definitions.

Table 1: Selected definitions of the term *supply chain disruption* and associated terms

Authors	Term	Definition
Craighead, Blackhurst, Rungtusanatham, and Handfield (2007)	Disruption	Unplanned and unanticipated event that disrupts the normal flow of goods and materials within the supply chain and, as a consequence, exposes firms within the supply chain to operational and financial risks.
Hendricks and Singhal (2003)	Glitch	A firm's inability to match demand and supply (production delays and shipment delays).
Manuj and Mentzer (2008b)	Risky event	Risk, i.e., loss multiplied with its probability, is the expected outcome of a risky event.
Marley (2006)	Disruption	Misshipment from a supplier that results in a stoppage of production for a customer.
Paulsson (2007)	Disruption	Interruption in the continuity of the normal supply chain flow with a negative result impact.
Tomlin (2006)	Disruption risk	Inability of supplier to deliver an order.

From a broader perspective, anomalous, threatening events are an intrinsic part of organizational life and have long attracted scholarly attention in organizational research. This phenomenon is more generally termed *organizational crisis* and started to receive attention in the management literature in the 1960s and

1970s (Fink, Beak, and Taddeo, 1971; Hermann, 1963; Smart and Vertinsky, 1977). The literature on this topic now spans the fields of disaster research, engineering, management, marketing, organizational behavior, psychology, political science, and sociology (for a review, see Pearson and Clair, 1998). As a consequence of this longstanding research tradition, there are now numerous definitions of the term *organizational crisis* and an abundance of descriptions of its attributes and dimensions (e.g., Hermann, 1963; Kovoov-Misra, Clair, and Bettenhausen, 2001; Mannarelli, Roberts, and Bea, 1996; Milburn, Schuler, and Watman, 1983; Pauchant and Douville, 1993; Pearson and Clair, 1998).

At the same time, there is a consensus that an organizational crisis entails (1) an unexpected triggering event, and (2) a consequential situation that threatens the organization by disrupting its normal course of operations (Billings, Milburn, and Schaalman, 1980; Hermann, 1963; Kovoov-Misra et al., 2001). Drawing from this literature, for the purpose of this dissertation, a *supply chain disruption* is defined as *the combination of (1) an unintended and unexpected triggering event that materializes somewhere in the supply chain or the supply chain environment, and (2) a consequential atypical situation which significantly threatens the normal course of business operations of the affected firms in the supply chain* (as depicted in Figure 1). Hence, in contrast to risk, a supply chain disruption is a manifested circumstance.

Given that organizational crises and supply chain disruptions are closely related phenomena, several additional insights and parallels can be derived from the rich literature on organizational crises and transferred to the supply chain context. Organizational crises have been described as requiring immediate attention (urgency), and as being outside the firm's complete control (Reilly, 1987). Their resulting performance impact is usually a function of time implying that response decisions must be made swiftly (Hermann, 1963). They are characterized by ambiguity of cause, effect, and means of resolution (Pearson and Clair, 1998). For the affected firms, they are exceptional and anomalous situations in comparison to

every-day business (Kovoor-Misra et al., 2001). Finally, it is important to note that a firm is experiencing a crisis or a supply chain disruption only if it is perceived as such (Hermann, 1963; Milburn et al., 1983). The decision makers' subjective perceptions of the situation, and not the actual facts, shape the organizational response (Child, 1972; Dutton, 1986; Håkansson, 1982; Mintzberg, Raisinghani, and Théorêt, 1976).

2.3 Supply chain risk sources

Supply chain disruptions, as outlined in the previous section, can materialize from inside or outside of a supply chain and can vary greatly in their magnitude, attributes, and effects. Consequently, their nature can be highly divergent. For instance, a delayed shipment of non-critical material is potentially a much less serious supply chain disruption than is an eight-week labor strike at a single-sourced key supplier. In attempting to differentiate supply chain disruptions from other adverse events in business (e.g., shocks on the financial markets), many scholars have proposed classifications of supply chain disruption in the form of typologies and/or taxonomies¹ (e.g., Cavinato, 2004; Chopra and Sodhi, 2004; Christopher and Peck, 2004; Hallikas, Karvonen, Pulkkinen, Virolainen, and Tuominen, 2004; Manuj and Mentzer, 2008a; Norrman and Lindroth, 2004; Spekman and Davis, 2004; Svensson, 2000). The derived categories of supply chain disruptions are usually labeled *supply chain risk sources*, in terms of being a known source from which supply chain disruptions emerge with a certain probability.

Jüttner (2005), for instance, defined supply chain risk sources as “any variables which cannot be predicted with certainty and from which disruptions can emerge” (p. 122). In this regard, operating a production plant constitutes a risk source, because it is associated with various known risks (e.g., fire). For example, Svensson (2000) named two supply chain risk sources (quantitative and qualitative),

¹ Typologies and taxonomies are *classifications*, i.e., groupings of entities by similarity. A *typology* is theoretically constructed, while a *taxonomy* is derived from empirical data (Bailey, 1994).

Jüttner (2005) delineated three (supply, demand, and environmental), and Manuj and Mentzer (2008a) proposed eight (supply, operational, demand, security, macro, policy, competitive, and resource).

Table 2: Supply chain risk sources and selected examples

		Risk sources				
	Demand side	Supply side	Regulatory, legal, and bureaucratic	Infrastructure	Catastrophic	
Definition	Arise from downstream supply chain operations.	Arise from upstream supply chain operations.	Arise from non-compliance with laws, rules, regulations, or ethical standards, as well as from regulatory, legal, or administrative barriers.	Arise from the infrastructure a firm maintains for its operations.	Arise from catastrophic events, i.e., events that have a severe impact in the area of occurrence.	
Examples	Disruptions in the material flow to the end-customer Supplier business risks (e.g., supplier default) Bullwhip effect Opportunistic behavior by customers	Quality problems Opportunistic behavior by suppliers Price volatility on supply markets Shortages Customer business risks (e.g., insolvency)	Non-conformance to environmental standards Trade barriers, e.g., tariffs or local content requirements	Disruptions in the supply of electricity or water Local human-centered issues	Natural hazards Terrorism Socio-political crises Diseases or epidemics	

As shown in Table 2, for the purpose of this dissertation, a classification in five distinct supply chain risk sources is proposed: (1) *demand side*, (2) *supply side*, (3) *regulatory, legal, and bureaucratic*, (4) *infrastructure*, and (5) *catastrophic*. In contrast to the other typologies, this classification represents an empirically substantiated taxonomy. The results of the exploratory factor analysis (EFA) are presented in Chapter 2 (details appear in Table 6). While the first two risk sources deal with supply-demand coordination issues that are internal to the supply chain, the latter three focus on risk sources that are not necessarily internal to the supply chain. In the next sections, the five risk sources are delineated. As it is virtually

impossible to enumerate every potential supply chain disruption, the following discussion focuses on the most common.

2.3.1 Demand side risk

Supply chain disruptions can emerge from downstream supply chain operations. These include, on the one hand, disruptions in the physical distribution of products to the end-customer which are usually associated with transportation operations, such as a truck drivers' strike (McKinnon, 2006), and the distribution network. On the other hand, demand side supply chain disruptions can originate from the uncertainty caused by customers' unforeseeable demands (Nagurney, Cruz, Dong, and Zhang, 2005). Here, disruptions may be the results of a mismatch between a company's projections and actual demand, as well as of poor coordination of the supply chain. The consequences of such demand side disruptions are costly shortages, obsolescence of stocks, poor customer service due to unavailable products or backlogs, or inefficient capacity utilization. An important issue in this context, affecting forecast quality and therefore demand side risk, is the bullwhip effect. The bullwhip effect occurs in forecast-driven supply chains and refers to the magnification of demand volatility as orders move up the supply chain (Forrester, 1958; Lee, Padmanabhan, and Whang, 1997a). Major factors contributing to the bullwhip effect are delayed and distorted information, sales promotions, order batching, price fluctuations, and rationing/shortage gaming (Lee, Padmanabhan, and Whang, 1997b), over-reactions, unnecessary interventions, second guessing, and mistrust (Christopher and Lee, 2004).

Although demand side risk management can be regarded, in some respects, as the "bread-and-butter discipline" of supply chain management, the delineated issues still present a major risk source for many firms. Cisco Systems, for example, had to write off US-\$2.5 billion in inventory in 2001 due to a lack of communication among its downstream supply chain partners (Spekman and Davis, 2004).

2.3.2 Supply side risk

Kraljic (1983) was among the first who emphasized that firms should proactively assess and manage the risks in their supplier portfolio in order to guard against costly supply disruptions. The need to assess and manage supply side risks carefully has only been intensified by stronger reliance on external sources for critical materials and components (Giunipero and Eltantawy, 2004). Firms are exposed to numerous potential supply chain disruptions stemming from the upstream side of their supply chains. Risks reside in purchasing activities, suppliers, supplier relationships, and supply networks. These risks encompass, in particular, supplier business risks, production capacity constraints on the supply market, quality problems, and changes in technology and product design (Zsidisin et al., 2000).

Supplier business risks relate to disruptions that affect the continuity of the supplier and result in the interruption or the termination of the buyer-supplier relationship. This is closely linked with the threat of financial instability of suppliers, and possible consequences of supplier default, insolvency, or bankruptcy (Wagner, Bode, and Koziol, 2007; Wagner and Johnson, 2004). The financial default of a supplier (e.g., a supplier going out of business) is a common supply chain disruption that can have severe consequences for the buying firm. The UK-based automotive OEM Land Rover, for example, found itself in serious trouble after its single supplier of chassis frames for its Discovery model, UPF-Thompson, suddenly and unexpectedly folded in 2001. KPMG, which represented the UPF-Thompson's receivers, exploited the single source relationship and virtually held Land Rover for ransom demanding £35 million to resume production (Lester, 2002).

Another type of disruption can occur when a supplier is vertically integrated by a direct competitor of the customer firm, forcing the termination of the relationship (Chopra and Sodhi, 2004). In buyer-supplier relationships that involve high switching costs for the buying firm, opportunistic behavior from suppliers has

also been reported to be a source of supply side risk (Spekman and Davis, 2004; Stump and Heide, 1996; Wagner and Hoegl, 2007; Wathne and Heide, 2000).

From unsolved problems in the suppliers' production and operations management, capacity constraints or shortages as well as poor logistics performance (delivery reliability) can occur (Lee and Billington, 1993). The bullwhip effect plays a role here as well, albeit from the opposite perspective. It has the same symptoms as outlined in the previous section. Furthermore, poor quality in the purchased products or services is a significant risk and can have a domino effect through the supply chain to the final customer (Zsidisin et al., 2000). Finally, the inability of suppliers to adapt to technological or product design changes may have detrimental effects on the customer's costs and competitiveness (Zsidisin and Ellram, 2003).

2.3.3 Regulatory, legal, and bureaucratic risk

With the exception of government initiatives for security facilitation such as the Customs-Trade Partnership Against Terrorism (C-TPAT) or Authorized Economic Operators (AEO) certifications (Sarathy, 2006; Zsidisin, Melnyk, and Ragatz, 2005a), little attention has been paid to supply chain risks stemming from regulatory and legal conditions. However, in many countries, authorities (administrative, legislative, and regulatory agencies) are a significant factor of uncertainty in the setup and operation of supply chains. Regulatory, legal, and bureaucratic risks refer to the legal enforceability and execution of supply chain-relevant laws, regulations, stipulations, or policies (e.g., trade and transportation laws) as well as the degree and frequency of changes in these rules. Such changes may suddenly lead to violations of (or nonconformance with) laws, rules, regulations, or ethical standards.

According to Hendricks and Singhal (2003; 2005a; 2005b), severe supply chain disruptions can be associated with the actions or decisions of authorities. Administrative barriers (e.g., customs, trade regulations) may restrict the setup and influence the operative performance of supply chains. This includes the ability to

obtain the approval necessary for supply chain design activities and supply chain operation but also trade barriers such as tariffs, embargos, import/export quotas, or local content constraints. In China, for example, local content requirements are a major barrier for the market entry of foreign firms (Kaufmann and Jentzsch, 2006). Another example was given by a logistics manager at a German technology company during one of the interviews conducted in the course of this dissertation project: in Russia, customs clearance is a major risk for inbound logistics. Here, risk arises from the unpredictable behavior of the Russian customs authorities, changing requirements concerning shipping documentation, stand-still fees, and possible time losses. For this reason, many importing firms work with expensive customs brokers that “facilitate” the clearance process.

Legal changes are often sudden and difficult to anticipate. For example, the introduction of the road pricing scheme for freight vehicles introduced in Germany in 2005 (Toll Collect²) has substantially increased transportation costs. Likewise, in many countries, environmental legislation now requires product traceability and the establishment of reverse logistics systems. In order to meet such environmental requisites, firms frequently become involved in more complex supply chains and hence incur higher supply chain costs.

2.3.4 Infrastructure risk

The infrastructure risk source includes potential disruptions that evolve from the infrastructure that a firm maintains for its supply chain operations. This includes socio-technical accidents such as equipment malfunctions, machine breakdowns, disruptions in the supply of electricity or water, IT failures or breakdowns, as well as local human-centered issues (e.g., vandalism, sabotage, labor strikes, industrial accidents) that are addressed within the area of supply chain security (Chopra and Sodhi, 2004; Lee and Wolfe, 2003; Spekman and Davis, 2004).

² Further information is provided at <http://www.toll-collect.de/> (as per August 28, 2008).

As many supply chain management functions build on information processing and sharing, problems related to information technology (IT) are highly relevant to supply chain risk management. In the last years, organizations have become increasingly technology-dependent and, consequently, vulnerable to IT-related issues or breakdowns of information technology infrastructure (Chopra and Sodhi, 2004; Engardio, 2001). These events can be the result of malevolent actions by individuals or groups (e.g., cyber-attacks, malicious software), software bugs, and hardware failures (Warren and Hutchinson, 2000). Moreover, modern Enterprise Resource Planning (ERP) systems force firms to open their internal processes and databases both to their suppliers and customers, thus increasing their exposure to IT-related threats.

2.3.5 Catastrophic risk

This class encompasses pervasive events that, when they happen, have a severe impact on the area of their occurrence. Such events can be epidemics or natural disasters, socio-political instability, civil unrest, and terrorist attacks (Kleindorfer and Saad, 2005; Martha and Subbakrishna, 2002; Swaminathan, 2003).

In many regions of the world, tsunamis, droughts, earthquakes, hurricanes, and floods are a constant threat to the societies and firms located there (Helferich and Cook, 2002; Munich Re, 2007). The negative consequences on supply chains are obvious, since production facilities and transportation systems are highly vulnerable to natural disasters. Due to the globalization of markets and a surge in globe-spanning supply chain operations, local catastrophes have increasingly indirect global repercussions.

The destructive impact of terrorism on firms' supply chains has received much attention since 2001 (Rice and Tenney, 2007; Sheffi, 2001). Terrorist acts affect supply chains either directly (e.g., destruction of logistics infrastructure) or indirectly (e.g., port closures for security reasons imposed by the government) (Czinkota, Knight, Liesch, and Steen, 2005). Ford, Toyota and DaimlerChrysler

experienced such indirect effects when border delays and shut-downs after September 11, 2001 caused massive disruptions to the flow of materials into their North American assembly plants. Toyota, for example, was forced to halt production at one US plant since parts shipped by air from Germany were delayed by the grounding of all US air traffic (Sheffi, 2001).

2.4 Supply chain vulnerability

While a supply chain disruption triggers a negative outcome, the disruption and its attributes (e.g., its magnitude) are not the sole determinants of the final outcome. The susceptibility of the supply chain is also of significant relevance to the harm caused by the supply chain disruption. This leads to the concept of *supply chain vulnerability*. The “Albuquerque fire” illustrates this concept (Latour, 2001). In 2000, a fire destroyed the entire production capacity of a semiconductor plant of Philips Electronics in Albuquerque, New Mexico (USA), a sub-supplier of comparable importance to the Scandinavian telecommunication equipment manufacturers Nokia and Ericsson, for several weeks. While Ericsson incurred a loss of about US-\$400 million, Nokia was able to manage the disruption and to mitigate the consequences. Disregarding the question of what Nokia did “right” or Ericsson did “wrong,” this example highlights that the characteristics of the supply chain disruption alone cannot determine the final impact on the affected firm. It seems that the exposure to or susceptibility of the supply chain to the event and its effects is also of great relevance to the final impact.

Research has contributed relevant insights to the construct of supply chain vulnerability and offers numerous definitions and approaches to it. However, its conceptual basis is still considered to be rather weak and insufficiently understood (Jüttner et al., 2003; Peck, 2005). Christopher and Peck (2004) defined supply chain vulnerability as “an exposure to serious disturbance” (p. 3). Svensson (2000; 2002) published several articles that shed light on the vulnerability construct. He distinguished atomistic from holistic vulnerability. Atomistic vulnerability is

limited to a part or a section of the supply chain (e.g., a single firm in the supply chain), while the holistic vulnerability covers the entire supply chain and all tiers. In the literature on natural hazards, vulnerability has been defined as a person's (or a group's) capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard (Blaikie, Cannon, Davis, and Wisner, 2003). In the context of maritime supply chains, Barnes and Oloruntoba (2005) described vulnerability as “a susceptibility or predisposition to (...) loss because of existing organizational or functional practices or conditions” (p. 519).

In this dissertation, a notion similar to the one proposed by Barnes and Oloruntoba (2005) is adopted and the atomistic perspective (supply chain vulnerability on the focal firm-level) is taken. Accordingly, it is suggested that supply chain vulnerability is a function of certain supply chain characteristics which make the focal firm sensitive to disruptions. The final loss that a focal firm incurs from a supply chain disruption is a result of its supply chain vulnerability and the characteristics (e.g., magnitude) of the disruption. Hence, supply chain vulnerability is the *ex ante* ability or inability of a firm to absorb the effects of a supply chain disruption.

This is in line with several articles which have argued that supply chain characteristics increase or decrease a firm's susceptibility to supply chain disruptions. For example, Craighead, Blackhurst, Rungtusanatham, and Handfield (2007) proposed that supply chain density, supply chain complexity, and node criticality increase the severity and impact of supply chain disruptions. From a safety psychology perspective, Reason (2000) argued that, often times, there are latent causes in an organization or in an organization's connections with the environment which require only a small triggering event to lead to a disaster. Such latent *pathogens*, that make firms particularly vulnerable, can be eroded safety procedures (Reason, 1990), “sloppy” management (Turner, 1994), or complexity and tight coupling in the technical systems or organizational processes (Perrow, 1984).

2.5 Supply chain risk management

In general, enterprise risk management can be defined as the “field of activity seeking to eliminate, reduce, and generally control pure risks“ (Waring and Glendon, 1998, p. 3). While the exact terminologies vary from author to author, a systematic risk management process usually comprises the stages of (1) risk identification, (2) risk analysis (including risk assessment and classification), (3) risk treatment (risk management in the narrow sense), and (4) risk monitoring (e.g., PMI Standards Committee, 2004). The overall objective of this process is to determine, implement, and monitor an optimal combination of measures to avoid, defer, reduce, or transfer all relevant risks. The determined mix is considered to be optimal if the remaining amount of risk is in line with the firm’s risk preference and its corporate strategy. Several authors have adapted this generic risk management process to the supply chain context (e.g., Hallikas et al., 2004; Khan and Burnes, 2007; Manuj and Mentzer, 2008a; McCormack, 2008; Ritchie and Brindley, 2007; Ziegenbein and Nienhaus, 2004).

Given the outlined process, tools and measures for the stages of (1) risk identification, (2) risk analysis, and (4) risk monitoring can be adopted without much modification from the general risk management literature (e.g., Freidank, 2000; Kajüter, 2003; Pfohl, 2002; Tummala and Leung, 1996; Wildemann, 2006). However, the third stage dealing with practices and measures of risk treatment in the supply chain context remains specific, and can therefore be regarded as *supply chain risk management* (in the narrow sense) (Tang, 2006a).

A large body of literature has proposed measures and activities of supply chain risk management (e.g., Chopra and Sodhi, 2004; Christopher and Peck, 2004; Elkins et al., 2005; Johnson, 2001; Lee and Wolfe, 2003; Manuj and Mentzer, 2008a; Manuj and Mentzer, 2008b; Martha and Subbakrahna, 2002; Rice and Caniato, 2003; Zsidisin et al., 2005a). Tang (2006a), for example, identified four areas where supply chain risk management activities can take effect: supply management, demand management, product management, and information

management. Kleindorfer and van Wassenhove (2004) cited two types of supply chain risk management activities: supply-demand coordination activities and activities for managing disruption risks.

This dissertation distinguishes cause- from effect-oriented practices of supply chain risk management. This classification is reasonable in this context, because it ties in very nicely with the proposed terminology framework. It can be explained in analogy to a soccer player. Following *causes-oriented risk management*, the soccer player can reduce or avoid the possibility of getting seriously injured by avoiding dangerous tackling. Following *effect-oriented risk management*, the soccer player can use protections (e.g., shin guards to protect the shins) to become more robust or can apply an ice spray to alleviate injuries. Hence, cause-oriented actions focus on eliminating the causes of supply chain disruptions, while effect-oriented actions focus on vulnerability.

2.5.1 Cause-oriented supply chain risk management

“If anything can go wrong, it will,” says *Murphy’s Law* (Matthews, 1995). If this holds true, a good risk management approach avoids or safeguards activities that are risky and “can go wrong.” *Cause-oriented supply chain risk management* practices attempt to achieve this, i.e., to reduce the occurrence probability of a supply chain disruption by aiming at its *causes*.

Risk avoidance implies the (almost) entire reduction of the occurrence probability of a supply chain disruption, simply by shunning risky activities. While this may not always be a practical option, it is possible for many types of disruptions (Kleindorfer and Saad, 2005). For example, switching from a financially instable supplier to a stable one avoids the threat of a sudden supplier default (Wagner and Friedl, 2007). Another example is the relocation of manufacturing operations from geographic regions with a high exposure to natural hazards to safer regions, in order to avoid the threat of being directly affected by such events.

Risk prevention encompasses a set of preventive activities and measures such as preparative safety and security initiatives. Here, the goal is not to avoid the risky activities itself, but to safeguard them in such a way that a severe supply chain disruption cannot emerge. Risk prevention is appropriate to limit such issues as vandalism, sabotage, fire, and some sorts of industrial accidents. Rice and Caniato (2003) distinguished physical security (e.g., access controls), information security (e.g., education and training of employees for information security), from freight security (e.g., the Customs-Trade Partnership Against Terrorism, C-TPAT) (Handfield, 2008).

Moreover, Zsidisin and Ellram (2003) emphasized that companies can reduce the occurrence probability of some supply chain disruptions by increasing the risk awareness of their suppliers and by driving a “risk culture” into the supply base. Sheffi (2005) even argued that competitors should collaborate to control common supply chain risks, citing the Technology Asset Protection Association (TAPA) which was founded in 1997 by Intel and other high-technology firms with the objective of setting standards for freight security.

Another powerful means of reducing the occurrence probability of supply chain disruptions, are approaches and initiatives that result in improved supply chain transparency and information exchange among supply chain nodes (suppliers, customers, distributors) (Grewal, Johnson, and Sarker, 2007). If the exchanged information is sufficiently understood, early warning signals can be interpreted and the looming disruptions addressed (Elkins et al., 2005).

Finally, supplier development can be effective in reducing supply side risk (Wagner, 2006b). If buying firms address deficient, and therefore risky, suppliers *ex ante* with appropriate supplier development activities, supply chain disruptions associated with such suppliers may be prevented.

2.5.2 Effect-oriented supply chain risk management

In case of *effect-oriented supply chain risk management* practices, a firm decides to bear certain risks, while attempting to limit or mitigate the negative consequences of a supply chain disruption. Such risk management efforts are effective when operations are sustained or quickly resumed, and organizational and external stakeholder losses minimized. Many of the risk handling activities proposed in the literature are effect- rather than cause-oriented.

In this context, two semantically very close terms are often used: *resilience* and *robustness*. *Resilience* is the ability of a supply chain (or of a firm in the supply chain) to recover and to bounce back into the original or desired state after being stressed by a supply chain disruption (e.g., Sheffi, 2005). *Robustness* is the ability of a supply chain (or of a firm in the supply chain) to resist a supply chain disruption, i.e., to have a low supply chain vulnerability (e.g., Christopher and Peck, 2004; Lummus, Melnyk, Vokurka, Burns, and Sandor, 2007). Effect-oriented supply chain risk management measures create such resilience or robustness. In other words, they minimize the level of damage in case of the occurrence of a supply chain disruption.

In general, this can be achieved by seeking redundancy for activities or resources which are particularly exposed to supply chain disruptions. Very common in practice are buffering strategies that enable firms to become tolerant to temporal resource shortages or delivery delays. The idea is to anticipate risk scenarios and to build slack (inventory, flexibility, or time buffers) into the supply chain. Not only does the slack ensure smooth processes, it also limits the damage to the supply chain and to the involved firms in case of a materializing supply chain disruption.

In the area of supply management and purchasing, the design of the supplier portfolio is a major target for effect-oriented measures. The common ex ante strategy to safeguard against the consequences of a sudden shortfall in supply, such as caused by a supplier default, is the diversification of the supply base (Anupindi

and Akella, 1993; Treleven and Schweikhart, 1988). The rationale behind this is to install redundancy by developing contingency supply sources in order to decrease the vulnerability to supply side supply chain disruptions (Sheffi and Rice, 2005). The buying firm can diversify order quantities and hedge against the sudden loss of a single supplier by having multiple competing suppliers (Tomlin, 2006).

Apart from improved forecasting of customer demands, substantial risk mitigation potential resides in the design of products as well as in the layout of the manufacturing processes. Advantageously modularizing products and standardizing components can support a manufacturing firm to become more flexible in its reaction to supply chain disruptions, and thus, in being better able to tolerate the uncertainties in both the supply and customer markets (Tang, 2006a). Common means in production and manufacturing are capacity buffers, stockpiling, and flexibility (e.g., through process postponement, shorter lead times, or flexible machinery).

Another important aspect is the creation of financial risk reserves which has to be considered to be an effect-oriented risk management measure. The risk bearing firm can build up financial reserves either on its own or it can transfer the risk to an insurance company that builds a collective reserve. Insurance companies offer many products pertaining to supply chain risks such as transportation insurance, inventory-related insurance (e.g., fire), or insurance against natural hazards (e.g., flooding) (Bode et al., 2007). A rather novel technique is the so-called Alternative Risk Transfer (ART) which provides coverage for very specific risks or for risks where no insurance product is available, such as catastrophic risks. Catastrophic risks (e.g., Gulf Coast hurricanes in the USA) can be placed at the capital markets by issuing corresponding catastrophe bonds or structured derivative products. The idea is to incur benefits in case an adverse event happens (Lewis, 2007). Unlike a traditional insurance contract, the risk is transferred to the capital markets (Lane, 2003).

Finally, business continuity plans or recovery plans are important tools to optimize the “firefighting” in the wake of a disruption (Gilbert and Gips, 2000). The impact of a supply chain disruption is a function of the time between the onset of the triggering event and the time when countermeasures take effect. Business continuity plans consist of proactively elaborated rules and processes that enable a firm to respond quickly to the situation and to prevent its escalation. They focus on limiting the impact of the disruptions and permitting the firm to continue operating close to normal (Zsidisin et al., 2005a). Certainly, it is impossible to create a universal business continuity plan for the unexpected, because there is an almost infinite number of possible supply chain disruptions. However, supply chain managers can increase their knowledge of, familiarity with, and ability to handle supply chain disruptions.

3 Research questions

The main body of this dissertation answers three research questions that are investigated in Chapters 2, 3, and 4.

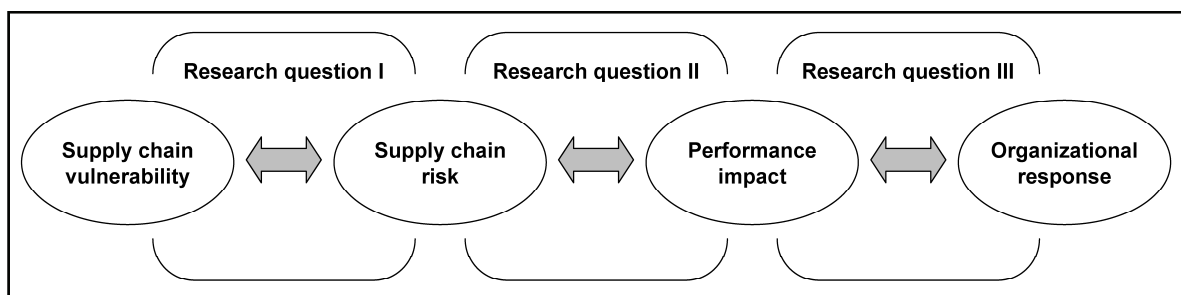


Figure 2: Overview of research questions

Figure 2 illustrates these three core research questions and their relationship with each other. The three conceptual frameworks developed and tested in each of

the three chapters take unique perspectives on the general theme of this dissertation, namely the phenomenon of supply chain disruptions.

3.1 Research Question I

As described in the previous section, supply chain vulnerability, despite having received ample attention in the recent literature, is still not sufficiently understood (Jüttner et al., 2003; Peck, 2005). In particular, knowledge of the mechanisms and conditions that determine the vulnerability of supply chains and about the interaction of supply chain vulnerability and supply chain risk is quite limited. The vast majority of research is normative, anecdotal, or case study-based. So far, only the event study-based research of Papadakis (2006) has shed empirical light on the vulnerability of supply chains. In 1999, a large earthquake hit Taiwan and, quite severely, the computer chip-industry located there (Burrows, 1999). Based on this event and on the set of publicly-traded computer manufacturers having suppliers in Taiwan, Papadakis compared the stock performance of computer manufacturers with make-to-order (MTO) supply chains and computer manufacturers with make-to-forecast (MTF) supply chains. The conclusion of this study was that the manufacturers' supply chain design affected their stock performance during and after a supply chain disruption. The study suggested that MTO supply chains are more vulnerable to supply chain disruptions than MTF supply chains are.

Still, this issue needs closer investigation. A better understanding of how supply chain characteristics and design are associated with supply chain vulnerability would enable supply chain managers to structure their supply chains in a way that brings them in line with their firms' willingness to take risks. Consequently, such knowledge would support better supply chain design. For instance, a firm seeking to take advantage of economies of scale in its inbound supply chain by pursuing a single sourcing strategy might simultaneously suffer from an increased exposure to supply side supply chain disruptions such as supplier defaults (Coleman and Jennings, 1998). While this relationship might seem to be

intuitive, it lacks conceptual development and empirically substantiated quantification. By adopting a theoretically underpinned model tested with survey data, the objective of Chapter 2 is to investigate the relationship between some supply chain characteristics, which are supposed to provoke the vulnerability of supply chains, and the impact on performance stemming from disruptions which originate from the five outlined supply chain risk sources. In summary, Research Question I is:

Question I: *Are there supply chain characteristics that are positively related with supply chain risk and, thus, can be conceived as drivers of supply chain vulnerability?*

3.2 Research Question II

As stated in the introduction, many researchers in supply chain management advise firms to take supply chain risks just as seriously as they take other business risks (e.g., Tomlin, 2006). The argument is compelling: Firms operate their supply chains in increasingly risky environments and therefore are forced to protect their operations and interests against adverse situations. However, supply chain risk management comes at a cost. Before firms engage in expensive risk management initiatives they need to have information about the (1) probability of occurrence of supply chain disruptions and (2) the effect of these disruptions on performance. In essence, supply chain risk management activities are only justified if supply chain risks interfere with supply chain performance.

So far, only Hendricks and Singhal (2003; 2005a; 2005b) have empirically investigated the relationship between supply chain risks and performance. Their three studies were based on a sample of public ad-hoc announcements from the *Wall Street Journal* and the *Dow Jones News Service* concerning supply chain disruptions. In two articles (Hendricks and Singhal, 2003; Hendricks and Singhal, 2005b), they examined how media announcements concerning supply chain

disruptions affected the observable share price and shareholder value of the announcing firm. The results demonstrated that stock markets penalize announcements of supply chain disruptions. The third article (Hendricks and Singhal, 2005a) focused on operating performance metrics observable through financial statement analysis (e.g., sales, operating income, ROA). By comparing the financial statements in the year preceding and following an ad-hoc announcement, Hendricks and Singhal were able to show that such announcements have a substantial long-term negative effect on operating performance. When Hendricks and Singhal investigated the relationship between *announced* supply chain disruptions and performance (shareholder value and performance indicators derived from financial statements), they did not differentiate among types of supply chain disruptions and, furthermore, did not consider the likelihood of their occurrence (as the sample contained only “unfortunate” firms that had *actually* suffered from a supply chain disruption). Therefore, the relationship between supply chain risk and supply chain performance has not been fully investigated. Thus, the goal of the research presented in Chapter 3 is to examine the link between the five supply chain risk sources and supply chain performance. This leads to Research Question II:

Question II: *Do supply chain risks have a significant impact on supply chain performance, and if yes, which supply chain risk sources are of relevance?*

3.3 Research Question III

A firm’s ability to learn from and respond to changes in its environment is critical to both its short-term competitiveness and its long-term survival (Argyris and Schön, 1978; Chandler, 1962; Lawrence and Lorsch, 1967). Such responses represent the firm’s attempts to influence its circumstances in an effort to improve its competitiveness (Aldrich, 1979; Child, 1972). Global competition has shaped complex, tightly coupled, and turbulent business environments in which adverse “surprises” and sudden changes, such as supply chain disruptions, are becoming

“normal” (Ansoff, 1975; Perrow, 1984). Appropriate strategies to mitigate or prevent supply chain disruptions have become more challenging to construct (Christopher and Lee, 2004). As described in the previous sections of this chapter, the vast majority of research on supply chain risk has focused on the causes of supply chain disruptions, on supply chain vulnerability, and on the cause- or effect-oriented management of supply chain disruptions. Significantly less attention has been paid to the aftermath of supply chain disruptions and, in particular, to the manner in which firms have adapted and responded to supply chain disruptions. Norrman and Jansson (2004) described how the Swedish telecommunications equipment provider Ericsson, in the wake of the “Albuquerque fire” incident mentioned in Section 2.4, reassessed and radically changed its supply chain risk management processes and organizational culture. Today, Ericsson has a world class supply chain risk management system (Norrman and Jansson, 2004; Swaminathan and Tomlin, 2007).

The case of Ericsson hints at a novel way of thinking about a supply chain disruption: to regard such incidents as an experience-based learning process (Levitt and March, 1988) that can expose the latent flaws and vulnerabilities of internal and external structures, processes, and systems (Meyer, 1982; Turner, 1976), thus helping the affected firm to understand the problems and improve its strategies for the future (Milburn et al., 1983; Nathan and Kovoov-Misra, 2002). The lean management philosophy, for example, deliberately uses this learning effect in a preemptive manner by systematically reducing operational slack with the intention of revealing and eliminating inefficient processes (Womack and Jones, 1996; Womack, Jones, and Roos, 1990). A well-known dictum from the Swiss novelist Max Frisch is that “crisis is a productive state; all you have to do is to remove the savor of catastrophe.”³ Similarly, one can argue that after experiencing a supply chain disruption, a firm seeks to cope with the experienced vulnerability and to

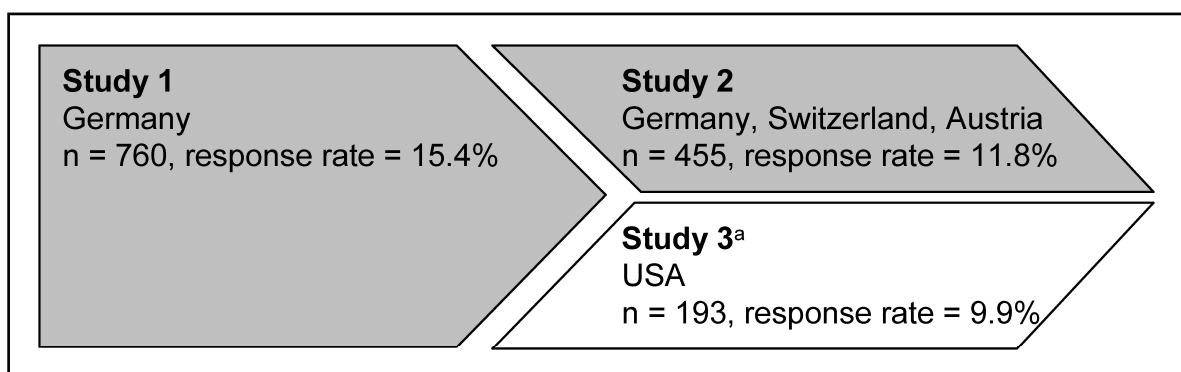
³ Originally in German: “Krise ist ein produktiver Zustand. Man muß ihm nur den Beigeschmack der Katastrophe nehmen” (quoted in Beier, Herkt, and Pollmann, 1997).

safeguard itself against future disruptions by reconsidering and changing its organizational rules, procedures, and external relationships. This leads to Research Question III:

Question III: *How does an organization respond to an experienced disruption?*

4 Empirical basis

To investigate the questions delineated above, theory-driven models were hypothesized which were subsequently tested on a broad empirical basis. Three large-scale data collection efforts were made (Study 1, Study 2, and Study 3). In all three studies, data were collected by means of a standardized, self-administered internet-based survey. The internet was chosen because it offers several advantages over traditional paper-based surveys, e.g., direct data entry to the database, fewer missing values, lower costs, and faster distribution (e.g., Boyer, Olson, Calantone, and Jackson, 2002). Several interviews with purchasing managers supplemented the data collection procedure. These results are not explicitly reported in this dissertation. The same applies to Study 3 which replicated Study 2 in the USA. Figure 3 depicts the process of data collection.



^a Results from Study 3 are not reported in this dissertation.

Figure 3: Data collection efforts in the course of the dissertation project

Research Questions I and II were investigated on the basis of Study 1, while Research Question III was examined using data collected in Study 2.

4.1 Study 1

4.1.1 Data collection procedure

A cross-sectional sample of 4,946 firms in Germany was surveyed between August and September of 2005. Contact addresses of these firms were obtained from a large industry database, with each respondent selected on the basis of job function, firm size (number of employees > 50), and industry sector. All surveyed firms were involved in some sort of material flow and handled tangible products (e.g., financial service firms were not considered). The unit of analysis in this study was the buying firm (focal firm) and its supply chains.

This study targeted single well-informed respondents (Kumar, Stern, and Anderson, 1993; Phillips, 1981). These respondents were senior managers with key responsibilities in purchasing, logistics, supply chain management, or general management who were likely to have an overarching view of their companies' supply chains and supplier activities (Hallenbeck, Hautaluoma, and Bates, 1999). The invitations to participate in the survey were sent by personalized emails containing a link to the internet-based survey instrument. On average, the entire questionnaire took 34 minutes to complete. In an effort to improve the response rate of this survey, respondents were offered a composite summary of the results and the chance to enter a lottery (chance of winning 1:100) in exchange for participation. The initial mailing, two follow-ups (two weeks and four weeks after the initial mailing), and a large number of reminder telephone calls, generated 760 usable responses, yielding a relatively high effective response rate of 15.4%, considering the time constraints of top-level executives (Baldauf, Reisinger, and Moncrief, 1999; Tomaskovic-Devey, Leiter, and Thompson, 1994).

Considerable attention was paid to the design of the survey instrument, its ease of use, the burden on the respondent, and the maintenance of the respondents' interest until the survey was completed (Dillman, 2006). The survey instrument was pre-tested with industry contacts and researchers familiar with empirical research in social sciences, in order to obtain feedback on the content, design, and usability of the survey website. Moreover, the survey instrument incorporated the recommendations of Podsakoff, MacKenzie, Lee, and Podsakoff (2003) for reducing common method bias. Accordingly, the respondents were offered anonymity and confidentiality to reduce the chances of responses that are socially desirable or consistent with how respondents believed researchers wanted them to respond. In order to reduce evaluation apprehension, the respondents were informed that there were no correct or incorrect answers and that they should respond as honestly as possible.

4.1.2 Sample characteristics

The sample covered industrial (71.7% of the sample), service (19.5%), and trade (8.8%) firms. Industries most frequently represented were logistics service providers (17.1%), automotive (11.2%), electrical, electronics, and optics (10.1%), and industrial equipment (9.5%). At the time of the survey, the firms' annual sales ranged from less than US-\$10 million to US-\$90 billion (mean = US-\$60.3 million), and the number of employees ranged from fewer than 100 to 430,000 (mean = 2,913 employees), thus yielding a heterogeneous sample. The informants provided € values which were converted into US-\$ values according to the official currency exchange rate of December 31, 2005 (€1 = US-\$1.18).

Table 3: Sample composition of Study 1

	Frequency Percentage	
Industries		
Industry sector	545	71.7
Automotive	85	11.2
Electrical/Electronic equipment; Optics	77	10.1
Industrial machinery; Machine tools	73	9.5
Chemicals; Pharmaceuticals; Plastics, Rubber	64	8.4
Telecommunications	50	6.6
Materials; Metal; Metal working	47	6.2
Food; Beverages	42	5.5
Paper; Packaging and related products	32	4.2
Construction	23	3.0
Consumer goods	19	2.5
Aerospace; Defense	16	2.1
Medical devices	10	1.3
Other industry	7	0.9
Service sector	148	19.5
Logistics services; Third-party logistics service providers (3PLs)	130	17.1
Other services	18	2.4
Trade sector	67	8.8
Number of employees		
Less than 100	163	21.5
100 – 249	181	23.8
250 – 499	140	18.4
500 – 999	88	11.6
1,000 – 4,999	116	15.3
5,000 – 9,999	21	2.8
10,000 or more	28	3.7
No response	23	3.0
Annual revenues (in US-\$)^a		
Less than 10 million	113	14.9
10 million – under 50 million	182	23.9
50 million – under 100 million	124	16.3
100 million – under 250 million	112	14.7
250 million – under 500 million	66	8.7
500 million – under 1 billion	51	6.7
1 billion – under 10 billion	55	7.2
10 billion or more	38	5.0
No response	19	2.5
Functional area of responsibility of respondents		
Logistics or supply chain management	285	37.5
General management	181	23.8
Purchasing; Procurement; Sourcing	114	15.0
Production	106	13.9
Sales; Distribution	27	3.6
Accounting; Finance	16	2.1
Other management	26	3.4
No response	5	0.7

^a The informants provided €-values which were converted into US-\$-values according to the official currency exchange rate of December 31, 2005 (€1 = US-\$1.18).

By functional area of responsibility, most of the respondents held management positions in logistics and supply chain management (37.5%), general management (e.g., Executive Vice President, Senior Vice President, or owner-managers) (23.8%), or purchasing/procurement (15.0%). A detailed breakdown of the sample and informants can be found in Table 3. Given the range and size of the firms studied and the diversity of industries, there was no *prima facie* reason to expect any systematic bias in the results.

Informants' knowledge on the topic under investigation and their ability to answer the questionnaire are major concerns in empirical studies using key informants (Kumar et al., 1993). Two indicators for the adequacy of the informants' knowledge are the informants' tenure (1) in the current position and (2) in the respective company. In the sample, the respondents have been in their current position for an average of 7.0 years and with their present company for an average of 10.9 years. This indicates good informant competence and experience with regard to the topic of this study.

4.1.3 Data examination

The data were thoroughly screened and analyzed for possible problems and inconsistencies. The univariate distributions of the manifest variables were examined for both skewness and kurtosis and found to be within acceptable ranges (i.e., skewness below |2.0| and kurtosis below |7.0|). No obvious univariate or multivariate outliers were detected by visual inspection and the examination of the Mahalanobis distances ($p < 0.001$) (Cohen, Cohen, West, and Aiken, 2003). No significant mean differences were detected between respondents from either of the functional areas of responsibility.

Non-response bias was assessed on the premise that later respondents would be similar to non-respondents (Armstrong and Overton, 1977). The data set was organized into two groups of equal size, one group of earlier respondents and one group of later ones. To assess whether there are statistically significant differences

between the two groups, *t*-tests were performed on the responses of the two groups. The performed *t*-tests ($p < 0.05$) yielded no statistically significant mean differences among all items used in the estimated models. This finding provides some support for the notion that the data are free from non-response bias.

4.2 Study 2

4.2.1 Data collection procedure

The experiences with developing the survey instrument for Study 1 and the data collection procedure were taken into consideration when preparing the survey instrument and the data collection for Study 2.

The population chosen for Study 2 consists of representatives from manufacturing firms in Austria, Germany, and Switzerland. To obtain an initial set of companies, contact details of managers with purchasing and supply chain management responsibilities in their firms ($N = 3,945$) were purchased from a commercial business data provider, with each respondent selected based on job function, firm size (number of employees > 50), and industry sector by SIC code. Companies that did not have their own purchasing responsibilities (meaning that purchasing decisions were made by a parent company) were excluded. The unit of analysis in this study was a (supply side) supply chain disruption as conceptualized in Section 2.2. Respondents were asked to base their answers on a specific supply chain disruption that occurred during the twelve months preceding the data collection *and* in which a specific supplier was involved – but not necessarily entirely responsible.

Similar to Study 1, target respondents were senior managers in the purchasing or supply chain department, who are likely to have an overarching, boundary-spanning view of their companies' supply networks and supplier activities (Hallenbeck et al., 1999). Using these contacts, respondents were invited to complete a self-administered internet-based survey between June and September

2007. The invitations to participate in the survey were sent by personalized emails containing a link to the survey instrument which, on average, took 30 minutes to complete. Respondents were offered a composite summary of the results as well as a practitioners' purchasing/supply management book in exchange for participation. After three follow-ups via email (two weeks, four weeks, and five weeks after the initial mailing) and reminder phone calls, 462 completed questionnaires were received. Seven questionnaires were discarded from this initial sample due to the informant's limited knowledge of the unit of analysis (see below), resulting in 455 usable questionnaires and an effective response rate of 11.5%. This response rate is considerably lower than the one obtained in Study 1, although it compares favorably to other recent surveys among supply chain management professionals (e.g., Gibson, Mentzer, and Cook, 2005; Sinkovics and Roath, 2004). An important issue in this regard is that 72 (1.8%) initially identified key informants *actively* replied to one of the mailings to communicate that their company had not been involved in a supply chain disruption in the last twelve months. This gives reason to assume that other potential respondents also may not have answered the questionnaire due to the lack of an appropriate supply chain disruption experience.

Again, considerable attention was paid to the design of the survey instrument, its ease of use, the burden on the respondent, and the maintenance of the respondents' interest until the survey was completed (Dillman, 2006). Prior to the initial mailing, the survey instrument was pre-tested with several purchasing and supply chain managers and discussed with a team of academics from purchasing, operations management, and supply chain management, all of them familiar with survey research. The feedback was used to improve format and clarity of the questionnaire and survey website. Keeping the concern of common method bias in mind, the respondents were offered anonymity and confidentiality to reduce the chances of responses that were socially desirable or consistent with how respondents believed researchers wanted them to respond. Moreover, the respondents were informed that there were no correct or incorrect answers and that

they should respond as honestly as possible to reduce evaluation apprehension (Podsakoff et al., 2003).

4.2.2 Sample characteristics

The participating companies represented a wide range of industry groups, the largest being industrial equipment (14.9% of the sample), electronics, optics, and medical devices (13.8%), and automotive (13.0%). The companies' annual sales volume in 2006 ranged from US-\$1 million to US-\$114.84 billion, the average being US-\$1.15 billion. The informants provided € values which were converted into US-\$ values according to the official currency exchange rate of December 31, 2006 (€1 = US-\$1.32). The number of employees ranged from less than 100 to 445,000 (mean = 2,978 employees). The majority of informants were senior managers (37.1%) or directors (31.9%) with their key responsibilities being purchasing or procurement (52.3%), supply chain management (15.4%), or general management (13.8%). The average age of the firms in the sample was 59.07 years (standard deviation = 45.66). A detailed breakdown of the sample is provided in Table 4. The data collection procedure yielded a heterogeneous sample covering a broad range of industrial sectors and firm sizes, revealing no indication for a systematic bias in the data set.

To assess the informants' knowledge on the topic under investigation and their ability to answer the questionnaire, three indicators were used: the informants' (1) tenure in the current position, (2) tenure in the respective company, as well as (3) experience in the purchasing, logistics, or supply chain management profession. In the sample, the respondents have been in their current position for an average of 6.7 years, with their present company for an average of 11.2 years, and have, in average, 14.3 years of work experience in the field of purchasing, logistics, or supply chain management. These values indicate satisfactory informant competence and experience with regard to the topic under study.

Table 4: Sample composition of Study 2

	Frequency	Percentage
Industries		
Industrial machinery; Machine tools	68	14.9
Electrical/Electronic equipment; Optics; Medical devices	63	13.8
Automotive	59	13.0
Chemicals; Plastics; Rubber	48	10.5
Metals; Metal working	48	10.5
Pharmaceuticals; Healthcare	28	6.2
Paper; Packaging and related products	26	5.7
Consumer goods	24	5.3
Engineering; Construction	23	5.1
Textiles and clothing	16	3.5
Food; Beverages	14	3.1
Aerospace; Defense	7	1.5
Telecommunications	6	1.3
Other industry	25	5.5
Number of employees		
Less than 100	43	9.5
100 – 249	133	29.2
250 – 499	94	20.7
500 – 999	62	13.6
1,000 – 4,999	76	16.7
5,000 – 9,999	10	2.2
10,000 or more	17	3.7
No response	20	4.4
Annual revenues (in US-\$)^a		
Less than 50 million	128	28.1
50 million – under 100 million	79	17.4
100 million – under 250 million	78	17.1
250 million – under 500 million	41	9.0
500 million – under 1 billion	31	6.8
1 billion – under 10 billion	30	6.6
10 billion or more	7	1.5
No response	61	13.4
Functional area of responsibility of respondents		
Procurement; Purchasing; Sourcing	238	52.3
Supply chain management	70	15.4
General management	63	13.8
Logistics	48	10.5
Production	25	5.5
No response	11	2.4
Titles of respondents		
Senior manager	169	37.1
Director	145	31.9
Vice president	49	10.8
President; CEO; COO; Manager-owner	35	7.7
Manager	28	6.2
Other	17	3.7
No response	12	2.6

^a The informants provided €-values which were converted into US-\$ values according to the official currency exchange rate of December 31, 2006 (€1 = US-\$1.32).

Moreover, the survey instrument included two additional questions to ensure the informants' ability to answer the questionnaire (Kumar et al., 1993). These questions assessed the respondents' knowledge about (1) the specific supply chain disruption and (2) the relationship to the involved supplier using a five-point rating scale (1: not knowledgeable at all – 5: extremely knowledgeable). The initially obtained sample ($n = 462$) contained seven respondents who marked "1" in either of the two questions, i.e., stated a very low knowledge with respect to one of these issues. Their responses were discarded to ensure the use of data from well informed respondents. In the effective sample, on average, the informants' responses indicated a very high degree of knowledge about the supply chain disruption (mean = 4.0) and about the relationship with the specific supplier (mean = 3.7), respectively. Most informants rated their knowledge about the supply chain disruption (74.2%) and the relationship (61.0%) within the range of 4 and 5. In sum, these evaluations provide support that the respondents were sufficiently knowledgeable and experienced.

4.2.3 Data examination

As in the case of Study 1, the data set was thoroughly screened and examined for possible problems and inconsistencies. The univariate distributions of all manifest variables were examined for both skewness and kurtosis; all values were within acceptable ranges (skewness below $|2.0|$ and kurtosis below $|7.0|$). No obvious univariate or multivariate outliers were detected by visual inspection and the examination of the Mahalanobis distances ($p < 0.001$) (Cohen et al., 2003). The manifest variables were also checked for differences across the groups of respondents (functional area of responsibility as well as titles), but no significant differences were found.

Two approaches were used to check whether non-response bias is a potential threat to the representativeness of the sample and thus to the validity of the findings. First, a wave analysis was conducted, based on the assumption that late respondents

are similar to non-respondents (Armstrong and Overton, 1977). *t*-Tests at the 5% level yielded no statistically significant differences among the responses from early (initial invitation email wave) compared to the late (second and third reminder email wave) respondents on all 28 items as well as on a few key demographic variables. Second, the sample of respondents was compared to a sample of 100 randomly selected non-responding companies drawn from the initial sample ($N = 3,945$) in terms of annual sales and employees in 2006. The data were gathered from an independent industry database. For both variables, no mean differences between respondents and non-respondents were found to be significant according to the performed *t*-tests ($p < 0.05$). In sum, although these results do not rule out the possibility of non-response bias, they speak against the existence of a major effect.

As the unit of analysis in this study is a supply chain disruption that occurred during the last twelve months prior to data collection, the study relies on the recall of prior experiences. Recall accuracy and recency effects, i.e., the tendency to be most influenced by recently received information (Carter, Kaufmann, and Michel, 2007), are arguably potential threats to the validity of the findings. Therefore, the survey instrument included a question asking the respondent for the exact date of the respective disruption. Following Srinivasan and Ratchford (1991), the data set was split into three equal groups of equal size based on the date of the disruptions. Then a multivariate analysis of variance (MANOVA) was performed to inspect mean differences across these three groups. At the multivariate level, no significant mean differences were found (Wilks's $\Lambda = 0.87$, $p = 0.35$) and at the univariate level (ANOVA), only one of the 28 items showed statistically significant mean differences at the 5% level. This result corroborates the assumption that recall effects are not a major problem with this data set.

Chapter 2 Supply chain vulnerability, its drivers, and the relationship with supply chain risk

This chapter investigates the relationship between supply chain vulnerability and supply chain risk. It is organized as follows. In Section 1, based on the nomenclature outlined in the previous chapter, the relevant literature, and selected theories, a conceptual framework and hypotheses elaborate the relationship between supply chain vulnerability and supply chain risk. Section 2 describes the methodology used to test the hypothesized relationships. Section 3 presents the results of the study. Finally, Section 4 discusses the findings and Section 5 draws on the implications for research and for managerial practice.

1 Theoretical background and hypotheses

In essence, two premises underlie the conceptual framework that will be developed in the next paragraphs. The first is that certain supply chain characteristics create supply chain vulnerability. The second is that there is a relationship between these drivers of supply chain vulnerability and the negative impact experienced by firms as a result of supply chain disruptions (supply chain risk).

1.1 Normal accident theory

Based on an in-depth analysis of a near-disaster at a US nuclear power plant,⁴ Charles Perrow proposed normal accident theory (NAT) that attempts to explain

⁴ A serious accident (partial meltdown) occurred on March 28, 1979 at the “Three Mile Island” nuclear power plant located near Harrisburg, PA, USA.

why complex socio-technical systems⁵ fail (Perrow, 1984). This theory links the occurrence and impact of system accidents (i.e., accidents that arise from the interaction among the system components rather than from the failure of an individual component) to the structure and technology of a system. The basic idea of Perrow's theory holds that two system characteristics are relevant for the probability of occurrence and the severity of system accidents: (1) *interactive complexity* of the system and (2) *tight coupling* of the elements in the system.

First, a socio-technical system such as a supply chain is complex, if it is characterized by a large number of (varied) elements that interact in a non-simple way (Choi and Krause, 2006; Simon, 1962). Obviously, with increasing levels of complexity, a system becomes more challenging to manage and control. However, according to normal accident theory, complexity is an essential, but not sufficient characteristic of high-risk socio-technical systems. Instead, it is argued that complexity becomes particularly dangerous, if the interactions among the system's components are nonlinear (*interactively complex system*). In Perrow's language, *linear* interactions lead to predictable and comprehensible event sequences, while *nonlinear* interactions lead to unexpected event sequences. He argued that interactively complex systems were "intellectually unmanageable," because the interactions among its components may result in unforeseen system behavior. Small, independent failures can interact in unplanned ways and produce unfamiliar, unexpected events that are not immediately comprehensible. In particular, the system's reaction to corrective actions is hard to predict, since positive or negative feedback loops may propagate, attenuate, or even reverse the intended effect in an unforeseeable manner.

Second, a system is tightly coupled, if the components are interrelated in such a manner that there are few possible substitutions, time-dependent processes,

⁵ The term *socio-technical system* was coined by Emery and Trist (1960; 1965) in the context of labor studies. The term refers to systems in which there is a close interrelationship between technical infrastructures and human individuals.

and minimal slack or buffers (Galbraith, 1973; Perrow, 1984; Weick, 1976). Often, tight couplings are accepted as the price for increased efficiency and high performance standards. For example, close collaboration between buyers and suppliers is usually advocated in current marketing and supply chain management textbooks. However, in tightly coupled supply chains, the margin of error is reduced. Similar to the domino effect, a change in one tier may trigger a rapid and strong change in related tiers. This implies that disturbances may propagate rapidly and spread almost unobstructed throughout the system. In contrast, loosely coupled systems are able to absorb failures, environmental changes, or unexpected system behavior.

In summary, both high levels of interactive complexity as well as high levels of tight coupling make a system vulnerable to accidents or disruptions. Given that a system combines both, it is virtually impossible to predict and protect against all the ways in which the system can fail. In such systems, Perrow insisted that accidents are inevitable, i.e., *normal*.

1.2 Supply chain vulnerability drivers

Normal accident theory offers an insightful underpinning for the investigation of supply chain vulnerability and its relationship with supply chain risk. As delineated above, normal accident theory suggests that a high degree of interactive complexity and a high degree of tight coupling lead to a higher frequency and a greater severity of accidents. Hence, drawing from this theory, it can be argued that a firm's exposition to supply chain risk is increased by the degree of interactive complexity and/or tight coupling in its supply chains (Christopher and Lee, 2004).

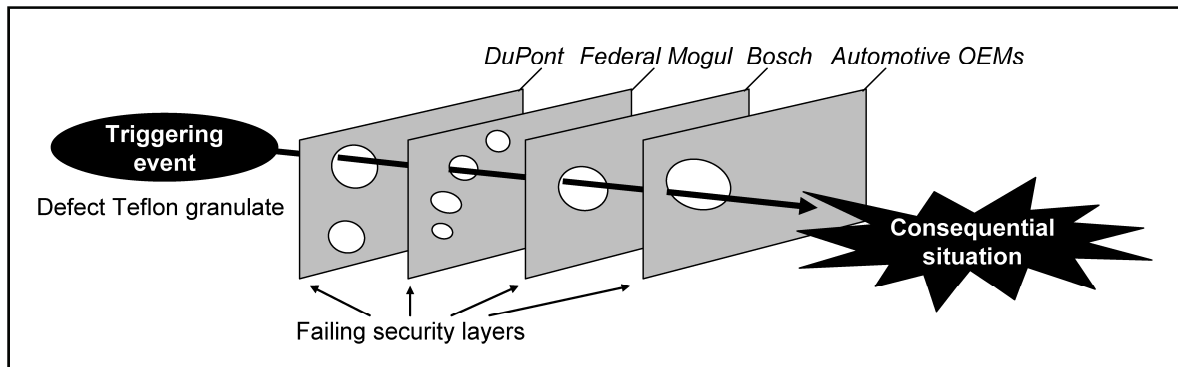


Figure 4: Supply chain disruption trajectory for the “Diesel injection pump” example

This is illustrated by a recent supply chain disruption experienced by Robert Bosch, the world’s largest auto-parts supplier (Wagner, 2006a). Figure 4 depicts this supply chain disruption. In January 2005, Bosch failed to detect a defect in the Teflon coating on a cheap 1.5 cm small socket that went into some of its diesel injection pumps supplied to automotive OEMs such as Audi, BMW, and Daimler. The interesting aspect of this incident is that the socket was not produced by Bosch itself, but by its US supplier Federal Mogul that in turn sourced the Teflon from the US chemical company DuPont. Downstream the supply chain, the faultily coated socket inside the diesel injection pumps brought some of the OEMs’ assembly lines to a standstill, triggered a product recall of several thousand cars with consequential costs in the three digit million € area, and tarnished the brand image of Bosch and the OEMs involved. Viewed through the lens of normal accident theory, this supply chain was interactively complex (because of the many actors, their different geographic locations, their different cultures, and their non-trivial interactions) and tightly coupled (low levels of buffers and slack, just-in-time deliveries), thus leading to a cascading sequence of failures and producing a serious supply chain disruption.

Several publications have mentioned supply chain characteristics that might increase or decrease the vulnerability of the supply chain. A thorough review of the literature yielded multiple statements that supply chain vulnerability is increased by *customer dependence* (Hallikas, Puumalainen, Vesterinen, and Virolainen, 2005;

Svensson, 2004), *supplier dependence* (Giunipero and Eltantawy, 2004; Hendricks and Singhal, 2005b; Jüttner, 2005; Spekman and Davis, 2004; Svensson, 2004), *supplier concentration* (Norrman and Jansson, 2004; Tang, 2006b; Zsidisin et al., 2000), *single sourcing* (Coleman and Jennings, 1998; Hendricks and Singhal, 2005b; Zsidisin, Ellram, Carter, and Cavinato, 2004), and *global sourcing* (Blackhurst, Craighead, Elkins, and Handfield, 2005; Jüttner, 2005; Kraljic, 1983; Peck, 2005; Peck, 2006; Seshadri and Subrahmanyam, 2005).

These statements were derived from case studies and anecdotes rather than from well-established theories. Normal accident theory is able to fill this gap and to explain parts of the relationship between supply chain vulnerability and supply chain risk. However, its core concepts of interactive complexity and tight coupling are hard to grasp in general, and in the supply chain context in particular. For example, the operationalization of the concept of tight coupling has proven to be difficult in the context of organizations (Wolf, 2001). For this reason, critics (e.g., Hopkins, 1999) have contended that normal accident theory is difficult to subject to empirical tests. While it might be hard to exhaustively capture the two concepts, it can be argued that the outlined supply chain characteristics are antecedent to interactive complexity and/or tight coupling, and therefore the following aspects are termed *supply chain vulnerability drivers*. In the following, these drivers are reviewed and linked to interactive complexity and tight coupling.

1.2.1 Customer dependence and supplier dependence

Dependence is a basic property of any exchange relationship: an entity A is dependent on an entity B to the extent that B controls some resource valued by A and that A cannot obtain this resource from alternative entities (Emerson, 1962). The dependence construct has been intensively investigated in buyer-supplier exchange relationships (e.g., El-Ansary and Stern, 1972; Lusch and Brown, 1996). According to Pfeffer and Salancik (1978), dependence in inter-firm exchange relationships is determined by (1) the importance of the exchanged resource, (2) the

discretion over the resource allocation and use, and (3) the extent to which there are alternatives for the resource (switching costs and alternative sources). At the same time, dependence is a mutual issue. That is, each partner can be dependent on the other: a buyer can depend on its supplier (supplier dependence) and a supplier can depend on its buyer (customer dependence) (e.g., Bensaou, 1999; Heide and John, 1988)

Supplier dependence has been viewed as the extent to which the focal firm sources important and critical inputs from one or more suppliers for which it has few alternatives or high switching costs (Hallikas et al., 2005; Hibbard, Kumar, and Stern, 2001). In such a setting, the focal firm is vulnerable since it has limited room for maneuvering and few bargaining opportunities (Bourantas, 1989). In case of a supply side supply chain disruption, the focal firm may experience significant problems in replacing the supply with a contingency source. The severity of the disruption impact is particularly amplified by the criticality of the purchased item and the magnitude of the exchange (Giunipero and Eltantawy, 2004; Pfeffer and Salancik, 1978).

Customer dependence is equivalent to supplier dependence, but transferred to a downstream relationship, i.e., the focal firm is dependent on some of its customers or, vice versa, some of the customers hold power. This dependence might stem from a high sales volume with a certain customer or specific (idiosyncratic) investments. In a supply chain disruption, the focal firm may be forced to bear a large portion of the impact because of the powerful customer(s).

The concept of dependence is very similar to the concept of tight coupling. Dependence implies that, in the short run, a relationship cannot be altered or changed (see also Section 2.2 in Chapter 4) (Caniëls and Gelderman, 2005). Hence, an adverse event that affects the supplier or the customer on which the focal firm is dependent, has direct repercussions on the focal firm. This suggests that supplier dependence and customer dependence are positively related to tight coupling.

1.2.2 Supplier concentration and single sourcing

Supplier concentration refers to the degree to which the supply market is dominated (e.g., in terms of market share) by a small number of competing suppliers. A high degree of supplier concentration implies that there is only a relatively small number of alternative sources for the buying firms. Consequently, such supplier concentration is also related to concentration of power (small number situation) (Pfeffer and Salancik, 1978; Porter, 1980; Williamson, 1975). There has been a recent trend to consolidate the supply base and at the same time to establish closer relationships with the suppliers in the smaller supply base (Ogden, 2006). Various benefits of supply base reduction efforts are cited in the literature such as improved product quality (Kekre, Murthi, and Srinivasan, 1995) or better relationships with the remaining suppliers (Ellram, 1991). However, the reliance on the external sources and the rationalization of the supply base affects supply chain vulnerability (Cavinato, 2004; Choi and Krause, 2006; Svensson, 2004). If a firm's sourcing activities are concentrated on a small number of suppliers (intentionally or not), it loses the flexibility to switch to contingency sources in disruptive situations. Moreover, under certain conditions (i.e., asymmetric power), the buying firm is exposed to a heightened risk of opportunistic behavior and organizational hold-up (Williamson, 1985). The issue of organizational hold-up is amply illustrated by the UPF-Thompson example cited in Section 2.3.2 of Chapter 1.

Single sourcing (also sole sourcing) is the ultimate form of supplier concentration and therefore the same issues apply. For this reason, the purchasing literature makes a strong case for not engaging in a single sourcing strategy without deliberately considering the consequences in terms of risk exposure arising from it (Berger, Gerstenfeld, and Zeng, 2004; Smeltzer and Siferd, 1998; Treleven and Schweikhart, 1988). Despite numerous benefits, single sourcing arrangements make a firm vulnerable to supply chain disruptions, as it is not feasible or costly to switch quickly to an alternative supplier in case of a disruption.

In summary, both supplier concentration and single sourcing can be said to contribute to “tight coupling” of supply chains. A triggering event that affects the suppliers or the material flow from them may directly lead to a supply chain disruption for the buying firm, because the supply cannot be easily replaced. In contrast, having multiple, competing, and not concentrated suppliers, the buying firm can diversify order quantities and hedge against sudden problems with one of the suppliers (Tang, 2006b).

1.2.3 Global sourcing

The benefits of global sourcing depend heavily on parameters such as the geographic location of the suppliers, the product purchased, or the mode of transportation. However, in comparison to sourcing from local markets, global sourcing is usually associated with increased uncertainty as well as poorer transparency and visibility. In addition, complicating factors that have to be tackled are longer lead-times due to long routes of transportation, reliance on critical infrastructures (ports, communication systems), taxes, duties, and fluctuations of exchange rates (Goetschalckx, Vidal, and Dogan, 2002). In general, global sourcing contributes to the structural complexity of the supply chain (Hendricks and Singhal, 2005b) and therefore increases supply side risk (Blackhurst et al., 2005; Das and Handfield, 1997).

In the organizational design literature, the concept of (structural) complexity has been split into three dimensions: vertical complexity, horizontal complexity, and spatial complexity (e.g., Daft, 2006). Transferring this framework to the supply chain context, it can be argued that global sourcing contributes to spatial complexity of the supply chain and therefore exacerbates supply chain complexity (Choi, Dooley, and Rungtusanatham, 2001; Choi and Hong, 2002; Choi and Krause, 2006; Vachon and Klassen, 2002). The reason is that global sourcing makes the supply chain more geographically dispersed, resulting in a physically elongated flow of goods with longer and more variable lead times (Crone, 2006).

1.3 Hypotheses

In summary, the previous paragraphs delineated that customer dependence, supplier dependence, single sourcing, and supplier concentration are related to tight coupling, while global sourcing is related to complexity. Viewed through the lens of normal accident theory, it can be expected that supply chains that exhibit high degrees of these characteristics (corresponding to higher degrees of complexity and tight coupling) experience more damage from supply chain disruptions over time.

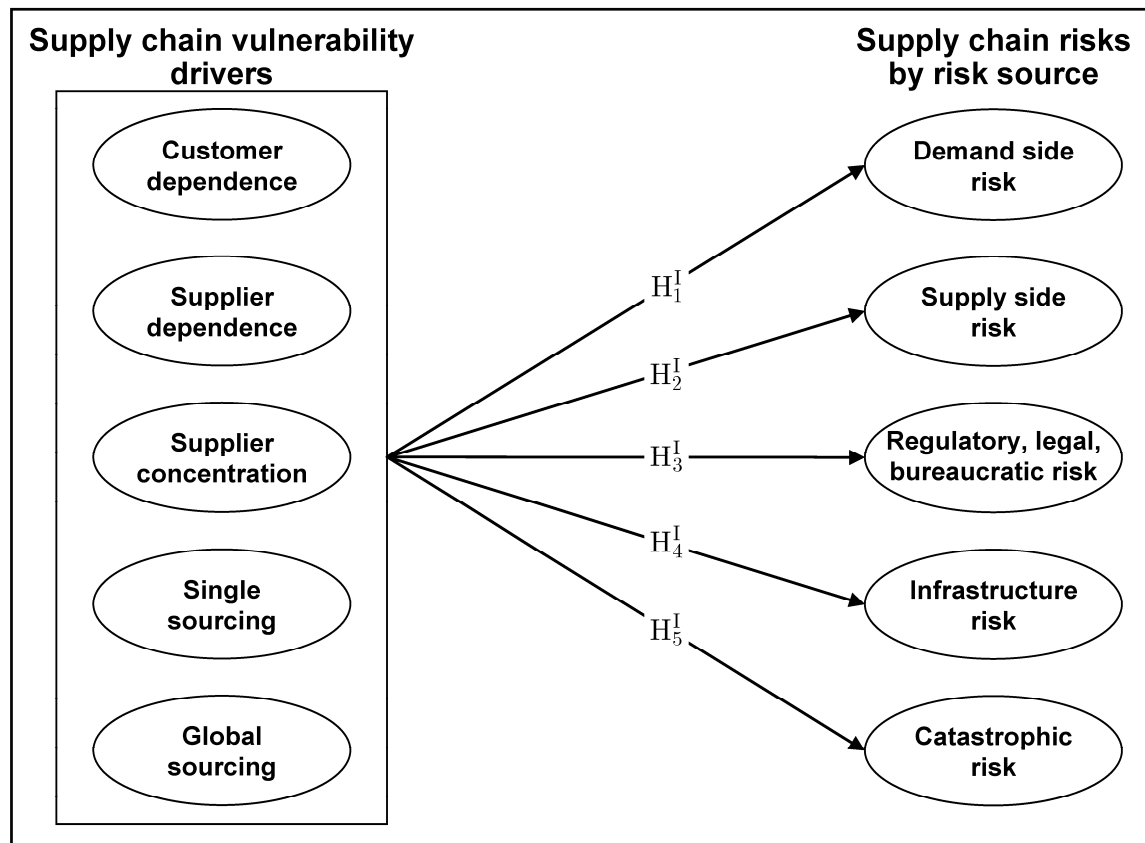


Figure 5: Conceptual framework I

Based on the fine-grained conceptualization of supply chain risk sources outlined in Chapter 1, the following five (aggregated) hypotheses are proposed:

Hypothesis H₁^I: *The higher the drivers of supply chain vulnerability, the higher the level of demand side risk a firm faces.*

Hypothesis H₂¹: *The higher the drivers of supply chain vulnerability, the higher the level of supply side risk a firm faces.*

Hypothesis H₃¹: *The higher the drivers of supply chain vulnerability, the higher the level of regulatory, legal, and bureaucratic risk a firm faces.*

Hypothesis H₄¹: *The higher the drivers of supply chain vulnerability, the higher the level of infrastructure risk a firm faces.*

Hypothesis H₅¹: *The higher the drivers of supply chain vulnerability, the higher the level of catastrophic risk a firm faces.*

The conceptual framework is depicted in Figure 5.

2 Methodology

2.1 Data and procedure

The proposed hypotheses were tested on a broad-empirical basis using the data set obtained from Study 1. The data collection procedure, the sample characteristics, as well as the statistical data examination were described in Chapter 1.

2.2 Measures

As indicated earlier, most previous studies on supply chain risk management are based on anecdotal evidence or case studies. Therefore, item batteries with formal scale characteristics that could have been used for the purpose of testing the outlined conceptual framework were not available. New measures and a fully standardized survey instrument were developed in several stages.

Table 5: Measures of constructs I

Construct name/Item (response cue)	Number of items	M	SD
Demand side risk (DSR)	2	3.25	0.99
<i>To what extent has your firm in the past three years experienced a negative impact in supply chain management due to... (1: not at all – 5: to a very large extent)</i>			
DSR1 Unanticipated or very volatile customer demand?		3.43	1.10
DSR2 Insufficient or distorted information from your customers about orders or demand quantities?		3.08	1.14
Supply side risk (SSR)	5	2.48	0.77
<i>To what extent has your firm in the past three years experienced a negative impact in supply chain management due to... (1: not at all – 5: to a very large extent)</i>			
SSR1 Poor logistics performance of suppliers (delivery dependability, order fill capacity)?		2.68	1.09
SSR2 Supplier quality problems?		2.80	1.04
SSR3 Sudden default of a supplier (e.g., due to bankruptcy)?		2.03	1.03
SSR4 Poor logistics performance of logistics service providers?		2.16	0.93
SSR5 Capacity fluctuations or shortages on the supply markets?		2.68	1.08
Regulatory, legal, and bureaucratic risk (BUR)	2	2.20	0.94
<i>To what extent has your firm in the past three years experienced a negative impact in supply chain management due to... (1: not at all – 5: to a very large extent)</i>			
BUR1 Changes in the political environment due to the introduction of new laws, stipulations, etc.?		2.31	1.12
BUR2 Administrative barriers for the setup or operation of supply chains (e.g., authorizations)?		2.08	1.03
Infrastructural risk (IFR)	4	1.73	0.68
<i>To what extent has your firm in the past three years experienced a negative impact in supply chain management due to... (1: not at all – 5: to a very large extent)</i>			
IFR1 Downtime or loss of own production capacity due to local disruptions (e.g., labor strike, fire, explosion, industrial accidents)?		1.56	0.84
IFR2 Perturbation or breakdown of internal IT infrastructure (e.g., caused by computer viruses, software bugs)?		1.80	0.88
IFR3 Loss of own production capacity due to technical reasons (e.g., machine deterioration)?		1.83	0.93
IFR4 Perturbation or breakdown of external IT infrastructure?		1.71	0.88
Catastrophic risk (CTR)	4	1.55	0.73
<i>To what extent has your firm in the past three years experienced a negative impact in supply chain management due to... (1: not at all – 5: to a very large extent)</i>			
CTR1 Political instability, war, civil unrest or other socio-political crises?		1.59	0.89
CTR2 Diseases or epidemics (e.g., SARS, Foot and Mouth Disease)?		1.61	0.92
CTR3 Natural disasters (e.g., earthquake, flooding, extreme climate, tsunami)?		1.47	0.87
CTR4 International terror attacks (e.g., 2005 London or 2004 Madrid terror attacks)?		1.51	0.84
Customer dependence (VULA)	1	3.35	1.27
<i>Please assess the following statement: (1: strongly disagree – 5: strongly agree)</i>			
VULA Our firm strongly depends on some of its customers.			
Supplier dependence (VULB)	1	3.35	1.27
<i>Please assess the following statement: (1: strongly disagree – 5: strongly agree)</i>			
VULB Our firm strongly depends on some of its suppliers.			
Supplier concentration (VULC)	1	2.81	1.11
<i>Please assess the following statement: (1: strongly disagree – 5: strongly agree)</i>			
VULC Our firm has concentrated its sourcing activities on a small number of suppliers.			
Single sourcing (VULD)	1	2.41	1.14
<i>Please assess the following statement: (1: strongly disagree – 5: strongly agree)</i>			
VULD Our firm frequently pursues single sourcing strategies.			

Construct name/Item (response cue)	Number of items	<i>M</i>	<i>SD</i>
Global sourcing (VULE)	1	3.00	1.37
<i>Please assess the following statement: (1: strongly disagree – 5: strongly agree)</i>			
VULE Our firm relies on a global supplier network (global sourcing).			
Firm size (SIZE)	1	2,913	19,104
<i>General question on your firm:</i>			
SIZE Total number of employees in 2004?			
<i>Note.</i> All items were measured on five-point rating scales (Likert-type). The construct mean is calculated as arithmetic mean of all scale scores.			

Measure development was based on procedures recommended by Churchill (1979) and DeVellis (2003). First, establishing the content validity of the survey instrument, the supply chain risk measures were based on an initial pool of scale items that had been generated through an extensive review of the academic and practitioner literature on supply chain risk management and supply chain management. Clear and unambiguous operational definitions for the risk measures and construct items were derived from these sources. A preliminary questionnaire was drafted. Second, the scale items included in the questionnaire, their relevance, their wording, and directions were refined on the basis of comments from practitioners and researchers. Third, to further refine the survey instrument, it was pre-tested through interviews with supply chain management managers from a small number of firms and several academics. This feedback was incorporated in the final version of the questionnaire.

The questionnaire asked the respondents to indicate (1) how their firms had been negatively affected by supply chain disruptions during the last three years prior to data collection (*supply chain risk*), and (2) how their supply chains were structured (*drivers of supply chain vulnerability*). The first point encompassed both the frequency and severity of all the supply chain disruptions a firm experienced during the three-year period, i.e., the cumulative loss incurred. Five-point Likert-type items were used to operationalize all constructs. All items were scored so that higher numbers reflect increases in the underlying constructs. Translations of the individual scale items, response cues for each measure, and descriptive statistics are listed in Table 5.

The *demand side risk* measure consisted of two items that capture the detrimental effects of the interaction (or lack thereof) with customers to be served through the downstream supply chain and volatility on the market (Hendricks and Singhal, 2003; Jüttner, 2005; Lee et al., 1997a; Towill, 2005). Likewise, *supply side risk* was measured with five items that capture the problems stemming from events and actors in the upstream supply chain, for instance, the supply market conditions and the performance of suppliers (Chopra and Sodhi, 2004; Zsidisin, 2003; Zsidisin and Ellram, 2003; Zsidisin et al., 2005a; Zsidisin et al., 2000). *Regulatory, legal, and bureaucratic risk* was assessed with a two-item scale related to changes in the political environment as well as administrative barriers imposed by governmental authorities (Hendricks and Singhal, 2003). *Infrastructure risk* was operationalized with a four-item scale directed towards IT, equipment, and facility malfunctions (Chopra and Sodhi, 2004; Spekman and Davis, 2004). For the *catastrophic risk* measure, a four-item scale was used that captures risks that originate from terrorist acts, socio-political crises, natural disasters, and epidemics (Chopra and Sodhi, 2004; Kleindorfer and Saad, 2005; Martha and Subbkrishna, 2002; Sheffi, 2001).

As mentioned above, a developed and validated measure for the supply chain vulnerability construct has not yet been proposed in the literature. With the literature review as point of departure, this study measured factors that are supposed to increase supply chain vulnerability, i.e., *supply chain vulnerability drivers*. Five single items were used, related to the dependence of the firm on some customers (customer dependence) and suppliers (supplier dependence), the concentration of the firm's supplier base (supplier concentration), the firm's application of single sourcing, and the firm's use of a global supplier base (global sourcing). These supply chain vulnerability drivers represent relatively simple, single-faceted, and unambiguous circumstances (e.g., single sourcing) (Bergkvist and Rossiter, 2007). Along the lines of Rossiter (2002) who remarked that a "concrete singular object to be rated in terms of a concrete attribute needs only a single-item scale" (p. 331), single items were used for the measurement of the supply chain vulnerability

drivers. Other advantages, such as simplicity and brevity of the survey instrument, are obvious.

As *firm size* can be a potential source of variance that confounds research findings, firm size was included as a control variable in the analyses when the effect of supply chain vulnerability drivers on supply chain risk was tested. This control variable was measured by a single item asking respondents for the number of employees in their firm (in 2004).

3 Statistical analysis and results

In line with Anderson and Gerbing (1988), the validity and reliability of the measures were demonstrated before testing the hypothesized relationships. Prior to these analyses, missing data analysis was performed which indicated that the few missing values (less than 4% of the total data points) were missing at random (MAR). Given the fairly large sample size, the small number of missing values, and the MAR condition, the listwise deletion method was chosen (Allison, 2001; Tsikriktsis, 2005).

3.1 Measure assessment

The validity and reliability of the measures was assessed by using both traditional psychometric approaches to scale assessment and confirmatory factor analysis (Hair, Black, Babin, Anderson, and Tatham, 2006; Mentzer and Flint, 1997; Nunnally and Bernstein, 1994). Results of the analyses of the multi-item measures are provided in Table 6. Inter-construct correlations, average variances extracted (AVE), and squared correlations are provided in Table 7. A table showing the inter-item correlations is provided in Appendix 3.

Table 6: Factor analysis results and measurement statistics I

Construct/Item	Coefficient alpha	Total variance explained	Item-to-total	Composite reliability	AVE	λ	t -value ^a	SE	IR
Demand side risk	0.57 ^b	0.78		0.74	0.59				
DSR1			0.57		0.69	– ^c	– ^c	0.61	
DSR2			0.57		0.82	11.20	0.11	0.59	
Supply side risk	0.80	0.56		0.91	0.67				
SSR1			0.70		0.79	– ^c	– ^c	0.77	
SSR2			0.69		0.77	20.51	0.05	0.78	
SSR3			0.55		0.62	15.97	0.05	0.59	
SSR4			0.50		0.61	16.14	0.04	0.62	
SSR5			0.48		0.58	14.95	0.05	0.52	
Regulatory, legal, and bureaucratic risk	0.53 ^b	0.77		0.77	0.63				
BUR1			0.53		0.70	– ^c	– ^c	0.61	
BUR2			0.53		0.76	11.18	0.09	0.65	
Infrastructural risk	0.75	0.57		0.85	0.58				
IFR1			0.59		0.66	– ^c	– ^c	0.61	
IFR2			0.58		0.71	11.66	0.10	0.63	
IFR3			0.50		0.62	13.99	0.07	0.50	
IFR4			0.51		0.66	10.97	0.10	0.59	
Catastrophic risk	0.85	0.70		0.92	0.74				
CTR1			0.76		0.85	– ^c	– ^c	0.81	
CTR2			0.67		0.78	24.12	0.04	0.75	
CTR3			0.67		0.72	18.73	0.04	0.68	
CTR4			0.68		0.72	18.82	0.04	0.70	

Note. All items were measured on five-point rating scales (Likert-type). λ refers to standardized factor loading, *SE* refers to standard error (asymptotically robust estimate), IR refers to indicator reliability.

^a *t*-values are from the unstandardized solution; all are significant at the $p < 0.001$ level (two tailed).

^b Bivariate correlation significant at the $p < 0.01$ level (see Appendix 3).

^c Factor loading was fixed at 1.0 for identification purposes.

Correlation analysis and principal component factor analysis (using varimax rotation) were performed. Only one factor was extracted for each scale with loadings always greater than 0.50. Reliabilities for all dependent variables were evaluated via item-to-total correlations and coefficient alpha (Malhotra, 2004; Nunnally and Bernstein, 1994). All items had a correlation with the total scores of above 0.35 which represents a common item-to-total cut-off indicating that an item should be deleted from the scale (e.g., Saxe and Weitz, 1982). The coefficients alpha ranged from 0.75 to 0.85, thus exceeding the common recommendations (e.g., Nunnally and Bernstein, 1994) and demonstrating high internal consistency of the scales.

In addition, reliability and validity of the measures were also assessed by means of confirmatory factor analysis (CFA) which is considered superior to the traditional criteria because of its less restrictive assumptions (Bagozzi, Yi, and Phillips, 1991). To this end, all independent variables (i.e., the supply chain vulnerability drivers measured by single items) and dependent latent variables were included in a single multifactorial CFA model, except for the control variable *firm size*. As proposed by Kline (2005), the five single-item measures were handled by fixing their factor loadings equal to one and their residual variance equal to zero. Given some indications for the presence of multivariate non-normality (normalized Mardia coefficient estimate = 42.68) the CFA model was estimated using the robust maximum likelihood estimation method of EQS 6.1 (Bentler, 1995; Curran, West, and Finch, 1996). Based on common recommendations on fit statistics for models of comparable size (e.g., Hair et al., 2006), the measurement model showed an acceptable fit to the data: Satorra-Bentler-scaled⁶ $\chi^2/df = 3.32$ (SB-scaled $\chi^2_{(164)} = 544.67$, $p < 0.001$), CFI = 0.91, NNFI = 0.87, GFI = 0.92, SRMR = 0.043, and RMSEA = 0.055 (90% confidence interval = [0.050, 0.060])⁷.

The CFA results indicate acceptable psychometric properties for all constructs showing that the used reflective items capture the respective underlying latent variables well and implying a satisfactory level of convergent validity and internal consistency. Without exception, each item loaded on its hypothesized factor with large and significant loadings (all significant at the 1% level). The indicator reliabilities are at an acceptable level, implying that the manifest variables are significantly influenced by their underlying latent variable and indicating that the scales are indeed unidimensional (Fornell and Larcker, 1981). Composite

⁶ The Satorra-Bentler-scaled (SB-scaled) χ^2 -static produced by the robust maximum likelihood method of EQS 6.1 incorporates a scaling correction based on the degree of multivariate non-normality. The adjustment is usually downward, because a lack of normality inflates χ^2 -statics (Chou, Bentler, and Satorra, 1991).

⁷ CFI stands for comparative fit index; NNFI stands for non-normed fit index (also Tucker-Lewis index, TLI); GFI stands for goodness-of-fit index; SRMR stands for standardized root mean square residual; RMSEA stands for root mean square error of approximation. An overview of these indices is provided in Kline (2005, p. 144).

reliabilities and average variances extracted of all constructs exceed the common cut-off values of 0.70 (Nunnally and Bernstein, 1994) and 0.50 (Bagozzi and Yi, 1988; Fornell and Larcker, 1981).

Table 7: Inter-construct correlations and average variances extracted (AVE) I

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) DSR	0.59	0.27	0.04	0.08	0.02	0.06	0.04	0.02	0.02	0.00
(2) SSR	0.52 ^{***}	0.67	0.22	0.20	0.12	0.00	0.10	0.00	0.06	0.07
(3) BUR	0.20 ^{***}	0.47 ^{***}	0.63	0.26	0.18	0.00	0.00	0.00	0.01	0.01
(4) IFR	0.28 ^{***}	0.45 ^{***}	0.51 ^{***}	0.58	0.13	0.01	0.02	0.01	0.03	0.00
(5) CTR	0.15 ^{**}	0.34 ^{***}	0.42 ^{***}	0.36 ^{***}	0.74	0.00	0.00	0.00	0.00	0.03
(6) VULA	0.24 ^{***}	0.05	0.07	0.12 ^{**}	0.02	1.00^a	0.06	0.01	0.02	0.02
(7) VULB	0.21 ^{***}	0.31 ^{***}	0.03	0.14 ^{**}	-0.03	0.25 ^{***}	1.00^a	0.10	0.16	0.00
(8) VULC	0.13 ^{**}	0.06	0.02	0.12 ^{**}	0.03	0.10 ^{**}	0.32 ^{***}	1.00^a	0.10	0.00
(9) VULD	0.14 ^{**}	0.24 ^{***}	0.09 [*]	0.18 ^{***}	0.03	0.13 ^{***}	0.40 ^{***}	0.31 ^{***}	1.00^a	0.01
(10) VULE	0.06	0.26 ^{***}	0.08	0.05	0.17 ^{***}	-0.15 ^{***}	0.07	0.05	0.10 ^{**}	1.00^a

Note. Diagonal values represent AVE values, squared correlations (shared variance) are in bold and above diagonal, Pearson correlation coefficients are below the diagonal. For discriminant validity above-diagonal elements should be smaller than on-diagonal elements.

^a Average variance extracted of single item measures is 1.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ (two-tailed).

Finally, discriminant validity was assessed on the basis of the criterion suggested by Fornell and Larcker (1981): as shown in Table 7, each construct extracts variance that is larger than the highest variance it shares with other constructs, thus providing support for discriminant validity.

In summary, the evidence provided in these analyses suggests that the measures included in this study possess sufficient reliability and validity to proceed with hypothesis testing. For hypothesis testing analysis, summated composites of the multi-item measures were calculated.

3.2 Regression model estimation and hypotheses testing

In order to test the proposed hypotheses, five linear models were independently estimated by means of multiple ordinary least squares (OLS) regression:

$$\begin{aligned}
\text{A. DSR} &= \alpha^A + \beta_1^A \text{VULA} + \beta_2^A \text{VULB} + \beta_3^A \text{VULC} + \beta_4^A \text{VULD} + \beta_5^A \text{VULE} + \beta_6^A \text{FSIZE} + \epsilon^A \\
\text{B. SSR} &= \alpha^B + \beta_1^B \text{VULA} + \beta_2^B \text{VULB} + \beta_3^B \text{VULC} + \beta_4^B \text{VULD} + \beta_5^B \text{VULE} + \beta_6^B \text{FSIZE} + \epsilon^B \\
\text{C. BUR} &= \alpha^C + \beta_1^C \text{VULA} + \beta_2^C \text{VULB} + \beta_3^C \text{VULC} + \beta_4^C \text{VULD} + \beta_5^C \text{VULE} + \beta_6^C \text{FSIZE} + \epsilon^C \\
\text{D. IFR} &= \alpha^D + \beta_1^D \text{VULA} + \beta_2^D \text{VULB} + \beta_3^D \text{VULC} + \beta_4^D \text{VULD} + \beta_5^D \text{VULE} + \beta_6^D \text{FSIZE} + \epsilon^D \\
\text{E. CTR} &= \alpha^E + \beta_1^E \text{VULA} + \beta_2^E \text{VULB} + \beta_3^E \text{VULC} + \beta_4^E \text{VULD} + \beta_5^E \text{VULE} + \beta_6^E \text{FSIZE} + \epsilon^E
\end{aligned}$$

For each equation, the critical assumptions underlying OLS multiple regression analysis were checked, i.e., (1) the residuals are normally distributed, (2) the residuals are of constant variance (homoscedasticity) over sets of values of the independent variables, and (3) multicollinearity of the independent variables is within an acceptable range (Cohen et al., 2003). To this end, each model was subjected a visual residual analysis using normal Q-Q plots: no obvious outliers were detected and residuals appeared to be approximately normally distributed. Homoscedasticity was checked using the Breusch-Pagan test ($p > 0.10$) and the Goldfeld-Quandt test ($p > 0.10$). Both tests indicated the absence of serious problem with heteroscedasticity. The bivariate correlations between the independent variables (shown in Appendix 3) were within acceptable ranges (i.e., bivariate correlation < 0.70) as well as the variance inflation factors (VIF) (i.e., VIF < 10), thus indicating that multicollinearity did not pose a serious problem to the regression analyses. In summary, these tests did not give reason to assume that the chosen method was inappropriate.

Table 8 provides the model summaries, the standardized parameter estimates, and the corresponding significance levels. The estimated regression results are depicted in Figure 6 (model A: demand side risk), Figure 7 (model B: supply side risk), Figure 8 (model C: regulatory, bureaucratic, and legal risk), Figure 9 (model D: infrastructure risk), and Figure 10 (model E: catastrophic risk).

Table 8: Results of model estimation I (OLS regression)

Dependent variables	Independent variables	β	<i>t</i> -value	f^2	Hypothesis relationship	Result	Model summary
Demand side risk (DSR)	VULA Customer dependence	0.17	4.49 ***	0.03	H ₁ ¹ : positive	Support	$R^2 = 0.07$
	VULB Supplier dependence	0.10	2.35 *	0.01	H ₁ ¹ : positive	Support	$F_{(6, 701)} = 8.58^{***}$
	VULC Supplier concentration	0.06	1.49		H ₁ ¹ : positive	No support	Post hoc power: 0.999
	VULD Single sourcing	0.05	1.10		H ₁ ¹ : positive	No support	
	VULE Global sourcing	0.07	1.79		H ₁ ¹ : positive	No support	
	Firm size (<i>control variable</i>)	-0.01	0.33		–	–	
Supply side risk (SSR)	VULA Customer dependence	0.00	0.08		H ₂ ¹ : positive	No support	$R^2 = 0.13$
	VULB Supplier dependence	0.23	5.64 ***	0.05	H ₂ ¹ : positive	Support	$F_{(6, 702)} = 16.83^{***}$
	VULC Supplier concentration	-0.05	1.42		H ₂ ¹ : positive	No support	Post hoc power: 0.999
	VULD Single sourcing	0.13	3.31 ***	0.02	H ₂ ¹ : positive	Support	
	VULE Global sourcing	0.18	4.94 ***	0.04	H ₂ ¹ : positive	Support	
	Firm size (<i>control variable</i>)	-0.02	0.54		–	–	
Regulatory, legal, and bureaucratic risk (BUR)	VULA Customer dependence	0.06	1.42		H ₃ ¹ : positive	No support	$R^2 = 0.01$
	VULB Supplier dependence	-0.03	0.62		H ₃ ¹ : positive	No support	$F_{(6, 700)} = 1.08^{n.s.}$
	VULC Supplier concentration	0.01	0.36		H ₃ ¹ : positive	No support	Post hoc power: 0.999
	VULD Single sourcing	0.06	1.32		H ₃ ¹ : positive	No support	
	VULE Global sourcing	0.04	1.15		H ₃ ¹ : positive	No support	
	Firm size (<i>control variable</i>)	0.03	0.91		–	–	
Infra-structure risk (IFR)	VULA Customer dependence	0.09	2.22 *	0.01	H ₄ ¹ : positive	Support	$R^2 = 0.04$
	VULB Supplier dependence	0.05	1.10		H ₄ ¹ : positive	No support	$F_{(6, 702)} = 4.90^{**}$
	VULC Supplier concentration	0.06	1.43		H ₄ ¹ : positive	No support	Post hoc power: 0.999
	VULD Single sourcing	0.11	2.53 *	0.01	H ₄ ¹ : positive	Support	
	VULE Global sourcing	0.02	0.62		H ₄ ¹ : positive	No support	
	Firm size (<i>control variable</i>)	-0.03	0.74		–	–	
Catastrophic risk (CTR)	VULA Customer dependence	0.05	1.32		H ₅ ¹ : positive	No support	$R^2 = 0.03$
	VULB Supplier dependence	-0.09	2.19 *	0.01	H ₅ ¹ : positive	Support	$F_{(6, 701)} = 3.48^*$
	VULC Supplier concentration	0.04	1.03		H ₅ ¹ : positive	No support	Post hoc power: 0.999
	VULD Single sourcing	0.03	0.63		H ₅ ¹ : positive	No support	
	VULE Global sourcing	0.16	4.07 ***	0.02	H ₅ ¹ : positive	Support	
	Firm size (<i>control variable</i>)	0.01	0.31		–	–	

Note. β refers to standardized OLS regression estimates. f^2 refers to effect size. Absolute *t*-values are shown.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ (one-tailed).

First, the outlined drivers of supply chain vulnerability explained 7% of the variance of demand side risk ($F = 8.58, p < 0.001$). H₁¹ posits a positive relationship between the drivers of supply chain vulnerability and demand side risk. This was supported by two factors that significantly increase demand side risk: strong customer dependence ($\beta_1^A = 0.17, p < 0.001$) and strong supplier dependence ($\beta_2^A = 0.10, p < 0.05$). The other independent variables showed no significant effect.

Second, the drivers of supply chain vulnerability explained 13% of the variance of supply side risk ($F = 16.83, p < 0.001$). H_2^1 positing that the identified drivers of vulnerability have a positive effect on supply side risk was confirmed for supplier dependence ($\beta_2^B = 0.23, p < 0.001$), single sourcing ($\beta_4^B = 0.13, p < 0.001$), and global sourcing ($\beta_5^B = 0.18, p < 0.001$).

Third, regressing the risk source regulatory, legal, and bureaucratic risk against the drivers of supply chain vulnerability, only 1% of the variance in bureaucratic risk was explained. The test on R^2 (i.e., that R^2 is significantly greater than zero) was not significant ($F = 1.08$). Hence, the hypothesis that there is no linear relationship between the predictor variables and the outcome variable cannot be rejected. None of the estimated relationships were significant, yielding no support for H_3^1 .

Fourth, the drivers of supply chain vulnerability explained 4% of the variance of infrastructure risk ($F = 4.90, p < 0.01$). H_4^1 , positing a positive relationship between the drivers of supply chain vulnerability and infrastructure risk, was supported for customer dependence ($\beta_1^D = 0.09, p < 0.05$) and single sourcing ($\beta_3^D = 0.11, p < 0.05$).

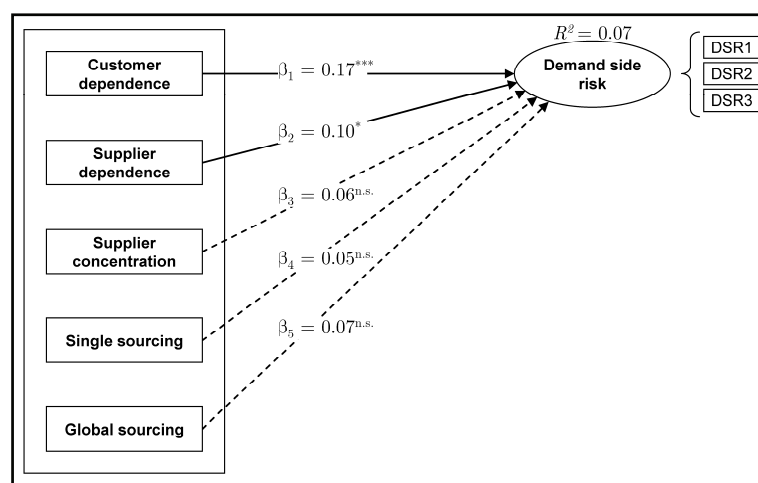


Figure 6: Results of model estimation I: Demand side risk (A)

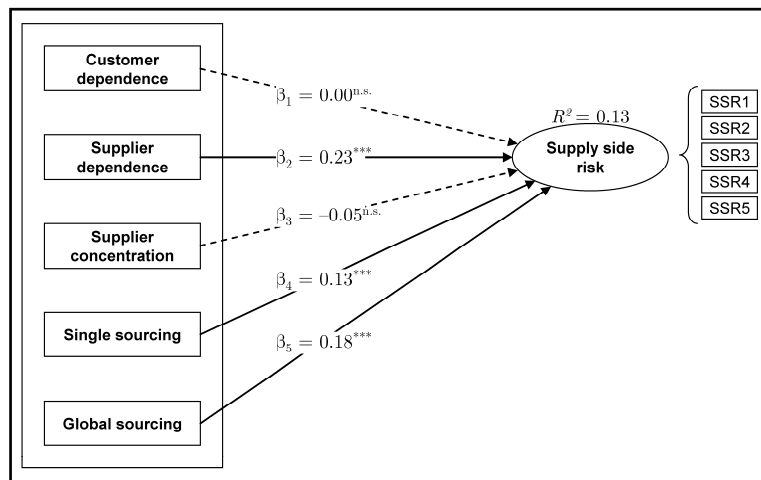


Figure 7: Results of model estimation I: Supply side risk (B)

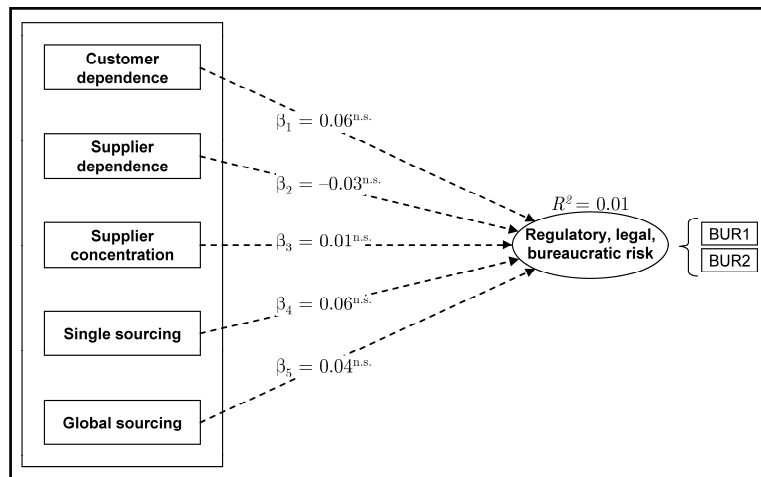


Figure 8: Results of model estimation I: Regulatory, legal, and bureaucratic risk (C)

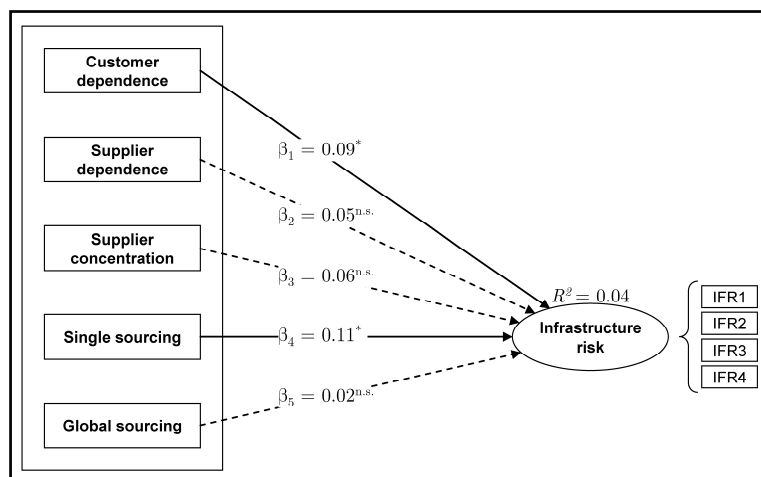


Figure 9: Results of model estimation I: Infrastructure risk (D)

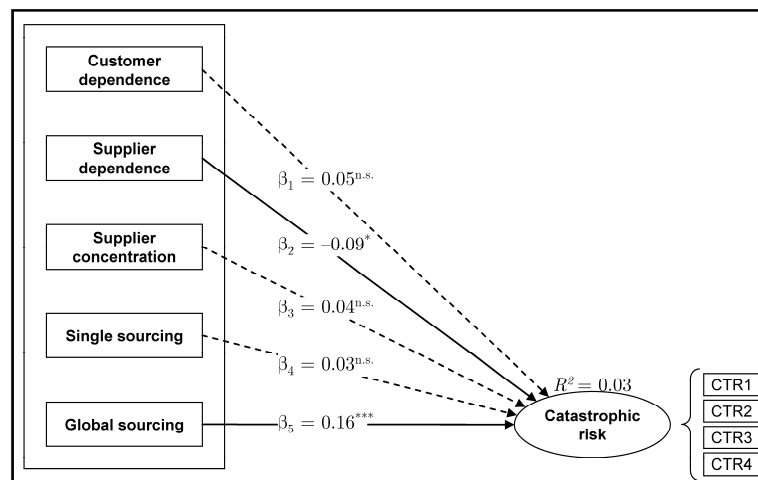


Figure 10: Results of model estimation I: Catastrophic risk (E)

Note. For purpose of clarity, control variable *firm size* is excluded.

Finally, in the fifth model, the drivers of supply chain vulnerability did not explain more than 3% of the variance of catastrophic risks ($F = 3.48$, $p < 0.05$). There was a highly significant positive relationship of a firm's reliance on a global sourcing network and the degree of catastrophic risk it experiences ($\beta_5^E = 0.16$, $p < 0.001$). This provides some support for H_5^{II} . In addition, a very slight but significant negative relationship ($\beta_2^E = -0.09$, $p < 0.05$) between strong supplier dependence and catastrophic risks exists, i.e., the more a firm depends on a few suppliers, the less negative impact it experiences from catastrophic risks. In each of the three estimated models, the control variable firm size showed no significant effect.

4 Discussion

By way of introduction, it is important to note that this study does not attempt to answer the question of how supply chain disruptions actually influence supply chain or firm performance. Accordingly, the results do not allow conclusions pertaining to the general relevance of supply chain risks. So far, only the important work of Hendricks and Singhal (2003; 2005a; 2005b) has yielded empirical insights into the relationship between supply chain disruptions and performance. Their results highlighted that stock markets severely penalize announcements of supply chain

disruptions. Moreover, the conceptual framework developed in this chapter does not address the direct causalities underlying supply chain disruptions. Therefore, the results do not allow conclusions such as “single sourcing causes supply chain disruptions.”

In contrast, based on a sample of 760 top-level executives in logistics and supply chain management (Study 1), the results shed light on the relationship between drivers of supply chain vulnerability and supply chain risk, i.e., the detrimental results from a disruption given certain supply chain characteristics. Starting with a literature review, this chapter identified and singled out several characteristics of supply chain design that are supposed to be relevant for a firm’s exposure to supply chain disruptions. Hence, the results explain how these supply chain characteristics increase or decrease the loss or damage to a firm from supply chain disruptions.

A first aspect to be discussed is that in each of the five estimated models the supply chain vulnerability factors explain a rather small portion of the variance in the dependent variables. Assuming that measurement errors are not the underlying issue, this is a clear indication that the conceptual framework omits variables which are relevant for the investigated relationship. With the five elaborated independent variables, the present research was a first attempt to reveal significant statistical relationships between supply chain design and supply chain risk. However, it seems to be intuitive that beyond the scope of the estimated linear models there are additional factors that drive supply chain vulnerability. This makes a strong case for the identification and investigation of further underlying factors by using theories that yield exploratory power on supply chain vulnerability such as normal accident theory (Perrow, 1984).

Concerning the first model (A), the results reveal that customer dependence is positively related to *demand side risk* (negative effects from volatile customer demand or information distortion). Thus, firms that are dependent on some customers are exposed to a higher risk of suffering from the detrimental effects of

demand volatility and poor downstream information. This is in line with the conceptual grounds delineated in Section 1. In addition, demand side risk is also increased by a dependence on the other side of the supply chain, namely supplier dependence. Being dependent on some suppliers generally implies a lack of switching options and weak negotiation power (Bourantas, 1989; Heide and John, 1988). Hence, in this case, a firm is less flexible on the supply side and consequently less capable of dealing with volatile demand and poor information from the demand side.

Second, risk derived from *supply side risk* sources is elevated by supplier dependence, single sourcing, and global sourcing. Supplier dependence obviously amplifies the threat from poor quality, supply shortages, sudden demise of one of these suppliers, and poor logistics performance. Although this argument also applies to single sourcing, the single sourcing approach seems to be less hazardous than general dependence on some suppliers. This might be because single sourcing is usually aligned with a closer relationship (e.g., long-term orientation, open communication, mutual trust and commitment, and joint activities) that might absorb some of the supply side risk (Elmaghraby, 2000). Nevertheless, single sourcing is a purchasing strategy that increases the exposure to supply side risk. Finally, given the numerous pitfalls associates with global sourcing (e.g., Trent and Monczka, 2002), this approach is in general a lever for supply chain risk (Blackhurst et al., 2005). Moreover, this research shows that global sourcing boosts particularly risk stemming from the upstream supply chain.

Third, the regression on the outcome variable *regulatory, legal, and bureaucratic risk* did not yield any statistically significant results, i.e., the five investigated supply chain vulnerability drivers did not have an impact on this risk source. Moreover, the test on the coefficient of determination was not significant, thus providing no support for the hypothesis that the linear relationship between the five independent variables and the outcome variable are different from zero in the population. A possible explanation could be that the employed two-item measure

might not have captured all of the regulatory, legal, and bureaucratic risk. However, the results must also be seen in the light of the political environment in which the data were gathered. Austria, Germany, and Switzerland are regions that are arguably very stable with regard to regulatory, legal, and bureaucratic issues. Therefore, the respondents might not have recently experienced any supply chain disruptions from this risk sources.

The estimates of the fourth model on the dependent variable *infrastructure risk* highlight that this risk is increased by customer dependence and single sourcing. Other predictors, however, do not directly impact on infrastructure risk. This result underscores the arguments that have been used against single sourcing in the literature (e.g., Treleven and Schweikhart, 1988; Wagner et al., 2007). If a firm operates on a single sourcing model, its technical core becomes highly dependent on the material flow from the single supplier. Therefore, single sourcing increases the risk of supply chain disruptions that affect a firm's infrastructure such as downtime of production capacity. Likewise, customer dependence increases the impact of supply chain disruption stemming from the infrastructure risk source. As mentioned above, customer dependence implies that customers have power over the focal firm. Hence, in case of a supply chain disruption that affects the technical core of the focal firm, the customers may tend to penalize the reduced performance (e.g., customers with low switching costs switch to competitors).

Fifth, when it comes to risk from *catastrophic risk* sources (natural disasters as well as anthropogenic catastrophes like terror attacks), it has to be taken into consideration that the sample data were collected in Germany, which has so far been a very "calm" place with regard to disasters. Here, only global sourcing is a significant factor that exposes firms to higher risk from catastrophes. The implementation of a global sourcing strategy stretches the supply chain geographically, which ultimately creates more peril points for the information and material flow. The robustness and resilience of regional or national supply chains are usually higher. Surprisingly, the study supports that supplier dependence

decreases the risk exposure to catastrophes. An explanation for this finding might be some sort of cooperation in the supply base. This receives support from the recent example of the auto-part supplier Takata Corp. In March 2006, one of Takata's airbag production facilities was destroyed, but its customers (e.g., Honda, GM, and Daimler) did not face a disruption because Takata's competitors worked together in order to support their customers, the automotive OEMs (Nussel, 2006).

Overall, the findings from the five linear models estimated support the hypothesis that supply chain characteristics or design variables influence the exposure of the involved firms to the results of supply chain disruptions. However, the relevance of the defined supply chain vulnerability drivers is comparably low since they only marginally explain the variance in supply chain risk.

5 Managerial and research implications

The major objective of this research was to examine the relationship between a selection of supply chain characteristics and supply chain risk, and provide an empirical investigation of the supply chain vulnerability construct. Building on a thorough examination of the supply chain risk typologies provided by the literature, this research compiled and empirically validated constructs for different classes of supply chain risk sources by means of a large-scale survey in Germany.

A couple of managerial implications can be deduced from this study. The findings advocate the consideration of risk aspects in supply chain design. As shown, there are several supply chain design variables that amplify a firm's exposure to risk. In particular, an organization should certainly try to circumvent customer and supplier dependence. In cases where this is not a valid option, other means of improving the supply chain robustness should be considered such as more rigorous control mechanisms (Christopher and Lee, 2004; Perrow, 1984; Perrow, 1999). Single sourcing and global sourcing are powerful concepts in a stable

environment but have to be evaluated from a risk management perspective. The study gives reason to ask for an acceptable risk-benefit trade-off.

With the preliminary indications and perspectives provided in this research, a more extensive investigation of supply chain design variables, supply chain vulnerability, and supply chain risk would be highly relevant from both an academic and a practitioner point of view.

Chapter 3 The relationship between supply chain risk and supply chain performance

This chapter presents research that examines the relationship between supply chain risk and supply chain performance. In Section 1, the literature on contingency theory and strategic choice theory is reviewed. These theoretical frameworks are applied to the relationship between supply chain risk and supply chain performance and used to develop a conceptual framework and hypotheses. Section 2 describes the methodology used to test the hypothesized relationships. Section 3 presents the empirical findings. Section 4 discusses the results, and Section 5 suggests implications for managerial practice and future research.

1 Theoretical background and hypotheses

1.1 Contingency perspective, strategic choice theory, and strategic fit

A classical approach in strategic management research, also applicable to supply chain management, is to divide the concept of strategy into two aspects: *process* (how strategy is formed) and *content* (what is decided). Numerous researchers have focused on either one or the other and investigated the relationship between certain strategic variables and performance (Ketchen, Thomas, and McDaniel, 1996). Although this distinction and its usefulness have been extensively discussed, Pettigrew and Whipp (1993) indicated that, in addition to content and process, the internal and external *environmental context* of the organization plays an important role in decision making and should therefore be incorporated into this framework.

Empirical research by Ketchen, Thomas, and McDaniel (1996) confirmed this perspective.

This view is also supported by contingency theory that builds on the central assumption that high organizational efficiency and performance result when firms consider the context in which strategy is crafted and implemented (Donaldson, 2001). Contingency theorists empirically tested direct relationships between particular contextual (environmental) variables, organizational structure, and performance, and observed that different types of organizational structures prosper in different environmental settings (e.g., Burns and Stalker, 1961; Lawrence and Lorsch, 1967). However, the contingency perspective views strategies merely as necessary responses to the environmental conditions, i.e., a firm's structure converges towards a reasonable fit with the environment, otherwise the firm perishes. Contingency theory fails to explain how this strategic fit is achieved (Ketchen and Giunipero, 2004). Therefore, Child (1972) proposed strategic choice theory as an extension to the classic contingency perspective. Child argued that contingency theorists had placed too much weight on the external environment. The strategic choice perspective negates the pure deterministic relationship between context and organizational structure, contending that the decision makers have strategic choice when designing the structure of their organizations. While decision makers face the constraints imposed by the prevailing conditions in the task environment, they still have room for strategic maneuvering. For high efficiency and performance, decision makers must actively match their organizations' structure to the demands of their task environment, i.e., forces outside the decision maker's control. It therefore depends on the aptitude of the managers to accumulate, configure, develop, and use the strategic resources at their disposal in such a way that strategic fit is achieved with the environment. If the fit is *not* achieved, "opportunities are lost, costs rise, and the maintenance of the organization is threatened" (Child, 1972, p. 8).

The role of the *context* or the *environment* has received a great deal of attention both in strategic management research and in organizational theory. Various conceptualizations of the construct and its constituent elements exist. This chapter follows Duncan's (1972) definition of *environment* as "the totality of physical and social factors that are taken directly into consideration in the decision making behavior of individuals in the organization" (p. 314). This definition includes factors that are internal and external to the firm.

For the purpose of this research, supply chain risk sources are considered to be critical contextual variables in the task environment of a focal firm (internal and external to supply chain).

1.2 Hypotheses

Viewed through the lenses of strategic choice theory, matching or aligning organizational resources with an organization's context, and especially to environmental opportunities and threats, is a major task for decision makers (Jemison, 1981; Miles and Snow, 1978; Venkatraman and Camillus, 1984). In particular, the design of supply chains and the coordination of supply chain partners are major areas of strategic choice.

As stated in Chapter 1, the literature in the field of supply chain risk has suggested that supply chain risk sources pose a significant threat for which many organizations are not sufficiently prepared. According to the contingency perspective, it can be hypothesized that firms that have a high exposure to supply chain risk should exhibit low supply chain performance. Given that this hypothesis holds true, decision makers are well advised to consider supply chain risk for the strategic orientation of their supply chains and, if necessary, to align the supply chain design to this changed environment in order to achieve a strategic fit.

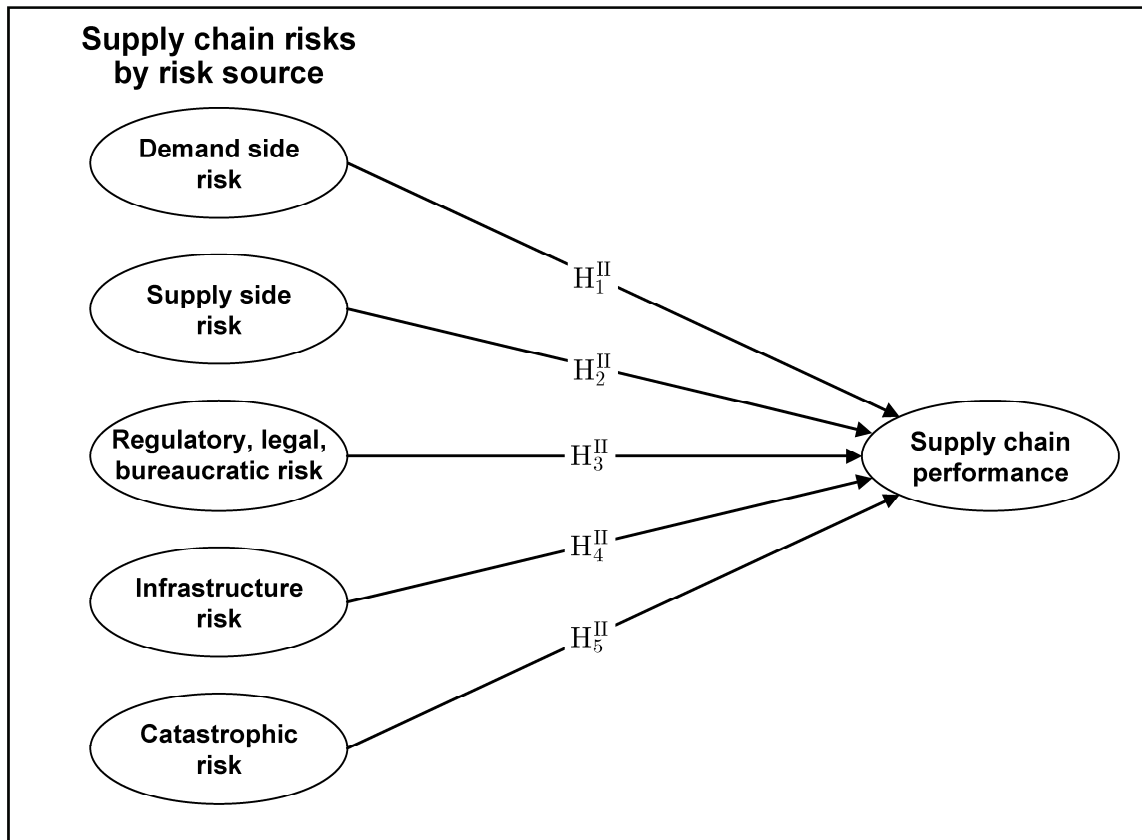


Figure 11: Conceptual framework II

This reasoning leads to the hypotheses and the conceptual framework depicted in Figure 11. The proposed framework posits that the risk deriving from supply chain disruptions of the five supply chain risk sources undermines supply chain performance, leading to:

Hypothesis H_1^{II} : *The higher the demand side risk, the lower the supply chain performance.*

Hypothesis H_2^{II} : *The higher the supply side risk, the lower the supply chain performance.*

Hypothesis H_3^{II} : *The higher the regulatory, legal, and bureaucratic risk, the lower the supply chain performance.*

Hypothesis H_4^{II} : *The higher the infrastructure risk, the lower the supply chain performance.*

Hypothesis H₅^{II}: *The higher the risks from catastrophes, the lower the supply chain performance.*

As mentioned before, if this finds empirical support, then the call for organizational adaptation towards supply chain risk is substantiated. This issue is closely linked to the question of effective and efficient supply chain risk management activities – as resources allocated to supply chain risk management could have been spent on other activities which might have been more profitable. Therefore, it is crucial to investigate which supply chain risk sources actually affect supply chain performance in order to address the “right” issues.

2 Methodology

2.1 Data and procedure

Similar to the research presented in Chapter 2, the hypotheses of this second conceptual framework were empirically tested with the data set gathered in Study 1. The data collection procedure, the sample characteristics, as well as the statistical data examination are described in detail in Chapter 1.

2.2 Measures

Except for the supply chain performance construct, multi-item measures with formal scale characteristics were not available for the purpose of this research. Therefore, as mentioned in Chapter 2, new measures and a fully standardized survey instrument were developed in several stages. Translations of the individual scale items and response cues for each measure are listed in Table 5 in Chapter 2 (*demand side risk; supply side risk; regulatory, legal, and bureaucratic risk; infrastructure risk; catastrophic risk*) and Table 9 (*supply chain performance; supply chain risk management*). All constructs were operationalized on five-point

rating-scales (Likert-type) and all items were scored so that higher numbers reflect increases in the underlying constructs.

Table 9: Measures of constructs II

Construct name/Item (response cue)	Number of items	M	SD
Supply chain performance (PFC)	4	3.77	0.62
<i>Evaluate the following supply chain performance indicators compared to your major competitor: (1: significantly worse – 5: significantly better)</i>			
PFC1 Order fill capacity: Provision of desired quantities on a consistent basis.		3.76	0.74
PFC2 Delivery dependability: Meeting quoted or anticipated delivery dates and quantities on a consistent basis.		3.79	0.75
PFC3 Customer satisfaction: Meeting customer satisfaction with supply chain performance on a consistent basis.		3.84	0.71
PFC4 Delivery speed: Time between order receipt and customer delivery.		3.70	0.76
Supply chain risk management (SCR) (Control variable)	6	2.73	0.87
<i>Indicate how the following statements apply to your firm: (1: does not apply at all – 5: applies very much)</i>			
SCR1 In collaboration with our customers and suppliers we are working on transparent supply chains and an open sharing of information.		3.14	1.20
SCR2 Our firm has elaborated business continuity or contingency plans addressing several supply chain risks.		2.73	1.33
SCR3 We regularly monitor our suppliers for possible supply chain risks.		3.01	1.15
SCR4 We reduce demand side risks through late product differentiation.		2.71	1.20
SCR5 In our firm, an employee or a team is dedicated to supply chain risk management.		2.18	1.28
SCR6 If possible, we insure against supply chain related risks.		2.61	1.21

Note. All items were measured on five-point rating scales (Likert-type). The construct mean is calculated as arithmetic mean of all scale scores. Measures for supply chain risk sources appear in Table 5.

The measures for the five supply chain risk sources are equivalent to those outlined and used in Chapter 2. As described there, respondents were asked to indicate how their firms had been negatively affected during the last three years by supply chain disruptions, and to specify their firms' supply chain risk management activities and supply chain performance.

In order to measure the dependent variable *supply chain performance*, a four-item scale that focuses on the downstream supply chain performance was adopted from Rodrigues, Stank, and Lynch (2004). They defined supply chain performance as the “ability of the firm to deliver specified value levels in a timely manner and to do so consistently” (p. 72). The four performance items are delivery dependability, order fill capacity, delivery speed, and customer satisfaction. Respondents were

asked to compare their firm's performance on these four aspects to that of their major competitor.

As the intention of this research was to investigate the effects of various supply chain risk sources on supply chain performance, but not the influence of supply chain risk management activities performed by the firms, it was necessary to include a *supply chain risk management* control variable. The measure was developed with the measures for the five supply chain risk sources; the scale development process is described in detail in Section 2.2 of Chapter 2. The final scale for supply chain risk management included six items based on risk management or mitigation strategies proposed in the literature (Chopra and Sodhi, 2004; Kleindorfer and van Wassenhove, 2004; Tang, 2006a).

3 Statistical analysis and results

Prior to the testing of the hypothesized relationships, the validity and reliability of the measures were assessed (Anderson and Gerbing, 1988). Missing data analysis on the manifest variables used in this model was performed, indicating that the few missing values (less than 4% of the total data points) were missing at random (MAR). Given the fairly large sample size, the small number of missing values, and the MAR condition, the listwise deletion method was chosen (Allison, 2001; Tsikriktsis, 2005).

3.1 Measure assessment

To assess the validity and reliability of the measures, both traditional psychometric approaches to scale assessment and confirmatory factor analysis were conducted (Hair et al., 2006; Mentzer and Flint, 1997; Nunnally and Bernstein, 1994). Results of the assessment of the multi-item measures are provided in Table 10. Inter-item correlations appear in Appendix 4.

Table 10: Factor analysis results and measurement statistics II

Construct/Item	Total Coefficient alpha	Item- variance explained	to- total reliability	Composite AVE	λ	t -value ^a	SE	IR
Demand side risk	0.57 ^b	0.78	0.72	0.56				
DSR1			0.57		0.67	— ^c	— ^c	0.59
DSR2			0.57		0.85	10.22	0.13	0.55
Supply side risk	0.80	0.56	0.90	0.67				
SSR1			0.70		0.79	— ^c	— ^c	0.76
SSR2			0.69		0.78	20.64	0.05	0.77
SSR3			0.55		0.62	16.19	0.05	0.59
SSR4			0.50		0.60	16.53	0.04	0.61
SSR5			0.48		0.58	14.94	0.05	0.50
Regulatory, legal, and bureaucratic risk	0.53 ^b	0.77	0.77	0.63				
BUR1			0.53		0.70	— ^c	— ^c	0.62
BUR2			0.53		0.76	11.70	0.07	0.65
Infrastructural risk	0.75	0.57	0.85	0.58				
IFR1			0.59		0.65	— ^c	— ^c	0.60
IFR2			0.58		0.72	12.18	0.10	0.65
IFR3			0.50		0.60	13.94	0.07	0.49
IFR4			0.51		0.67	11.54	0.09	0.61
Catastrophic risk	0.85	0.70	0.92	0.73				
CTR1			0.76		0.86	— ^c	— ^c	0.82
CTR2			0.67		0.78	24.80	0.04	0.75
CTR3			0.67		0.71	19.11	0.04	0.67
CTR4			0.68		0.72	19.25	0.04	0.68
Supply chain performance	0.85	0.69	0.93	0.78				
PFC1			0.78		0.81	— ^c	— ^c	0.82
PFC2			0.73		0.89	25.21	0.04	0.87
PFC3			0.63		0.69	19.81	0.04	0.70
PFC4			0.64		0.70	19.93	0.04	0.68
Supply chain risk management	0.79	0.50	0.89	0.58				
SCR1			0.66		0.77	— ^c	— ^c	0.74
SCR2			0.63		0.73	18.62	0.06	0.66
SCR3			0.60		0.68	17.22	0.05	0.67
SCR4			0.47		0.55	14.02	0.05	0.48
SCR5			0.47		0.54	13.54	0.06	0.43
SCR6			0.47		0.51	12.92	0.05	0.42

Note. All items were measured on five-point rating scales (Likert-type). λ refers to standardized factor loading, SE refers to standard error (asymptotically robust estimate), IR refers to indicator reliability.

^a t -values are from the unstandardized solution; all are significant at the $p < 0.001$ level (two tailed).

^b Bivariate correlation significant at the $p < 0.01$ level (see Appendix 4).

^c Factor loading was fixed at 1.0 for identification purposes.

Each factor was assessed using principal component factor analysis (varimax rotation). Following the Kaiser-criterion (Kaiser, 1974), only one factor was extracted for each scale with loadings always greater than 0.50. Reliabilities for all measures were evaluated via item-to-total correlations and coefficient alpha

(Malhotra, 2004; Nunnally and Bernstein, 1994). All coefficients alpha exceeded 0.70 (the lowest being 0.75), thus demonstrating high internal consistency of the scales (Nunnally and Bernstein, 1994). Next, item-to-total correlations were determined for each measure. All items had a correlation with the total scores of above 0.35 which represents a common item-to-total cut-off indicating that an item should be deleted from the scale (e.g., Saxe and Weitz, 1982).

Moreover, all independent and dependent latent variables were included in a single multifactorial confirmatory factor analysis (CFA) model. All measurement items were modeled as reflective indicators of the latent constructs. The model was tested using EQS 6.1 with the robust maximum likelihood estimation method, because the high normalized Mardia coefficient estimate of 44.98 hinted at multivariate non-normality (Curran et al., 1996). The overall fit of the CFA model provided for a Satorra-Bentler-scaled χ^2/df of 2.60 (SB-scaled $\chi^2_{(303)} = 788.34, p < 0.001$). Furthermore, the CFI was 0.92, the NNFI was 0.91, the SRMR was 0.042, and the RMSEA was 0.046 with a 90% confidence interval of [0.042, 0.050]. Given these results, the model showed a satisfactory fit to the data (Hair et al., 2006). On the basis of the estimates from this model, convergent and discriminant validity were scrutinized. Inter-construct correlations, average variances extracted, as well as squared correlations (i.e., shared variance) of each pair of constructs appear in Table 11.

Table 11: Inter-construct correlations and average variances extracted (AVE) II

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Demand side risk	0.56	0.26	0.04	0.08	0.02	0.02	0.00
(2) Supply side risk	0.51***	0.67	0.22	0.20	0.11	0.01	0.02
(3) Regulatory, legal, and bureaucratic risk	0.20***	0.47***	0.63	0.26	0.18	0.00	0.03
(4) Infrastructure risk	0.28***	0.45***	0.51***	0.58	0.12	0.02	0.01
(5) Catastrophic risk	0.14**	0.34***	0.42***	0.35***	0.73	0.00	0.02
(6) Supply chain performance	-0.14**	-0.12**	-0.04	-0.14**	-0.04	0.78	0.04
(7) Supply chain risk management	-0.05	0.15**	0.17***	0.08	0.13**	0.20***	0.58

Note. Diagonal values represent AVE values, squared correlations (shared variance) are in bold and above the diagonal, Pearson correlation coefficients are below the diagonal. For discriminant validity above-diagonal elements should be smaller than on-diagonal elements.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ (two-tailed).

In sum, the CFA results indicate good psychometric properties for all constructs. All factor loadings are greater than the common 0.40 cut-off (Nunnally and Bernstein, 1994) and significant at the 1% level. Moreover, all indicator reliabilities were above 0.40, indicating that the items were strongly influenced by the underlying construct and suggesting that the scales are indeed unidimensional. Composite reliabilities and average variances extracted of all constructs exceeded the common cut-off values of 0.70 (Nunnally and Bernstein, 1994) and 0.50 (Fornell and Larcker, 1981). Finally, discriminant validity was assessed on the basis of the criterion suggested by Fornell and Larcker (1981): as shown in Table 11, each construct extracted variance that is larger than the highest variance it shared with other constructs, thus providing support for discriminant validity.

In summary, the evidence provided in these analyses suggests that the measures included in this study possess sufficient reliability and validity to proceed with hypotheses testing. For hypotheses testing analysis, summated composites of the multi-item measures used in this study were calculated.

3.2 Regression model estimation and hypotheses testing

In order to test the developed hypotheses, the following linear model was estimated using multiple ordinary least squares (OLS) regression:

$$PFC = \alpha + \beta_1 DSR + \beta_2 SSR + \beta_3 BUR + \beta_4 IFR + \beta_5 CTR + \beta_6 SCR + \epsilon$$

The critical assumptions underlying OLS regression analysis were checked, i.e., (1) the residuals are normally distributed, (2) the residuals are of constant variance (homoscedasticity) over sets of values of the independent variables, and (3) multicollinearity of the independent variables is within an acceptable range (Cohen et al., 2003). To this end, the regression was subjected to a visual residual analysis using normal Q-Q plots: no obvious outliers were detected and residuals appeared to be approximately normally distributed. Homoscedasticity was checked using the Breusch-Pagan test ($BP = 0.40$, $p = 0.53$) and the Goldfeld-Quandt test

(GQ = 0.97, $p = 0.61$). Both tests did not indicate the presence of a serious problem with heteroscedasticity. The bivariate correlations between the independent variables (provided in Appendix 4) as well as variance inflation factors (VIF) were within acceptable ranges (i.e., bivariate correlations < 0.70 and VIF < 10). The largest VIF was 1.49, thus indicating that multicollinearity did not pose a serious problem to the regression analysis. In summary, the conducted tests provided no grounds to assume that the method chosen was inappropriate.

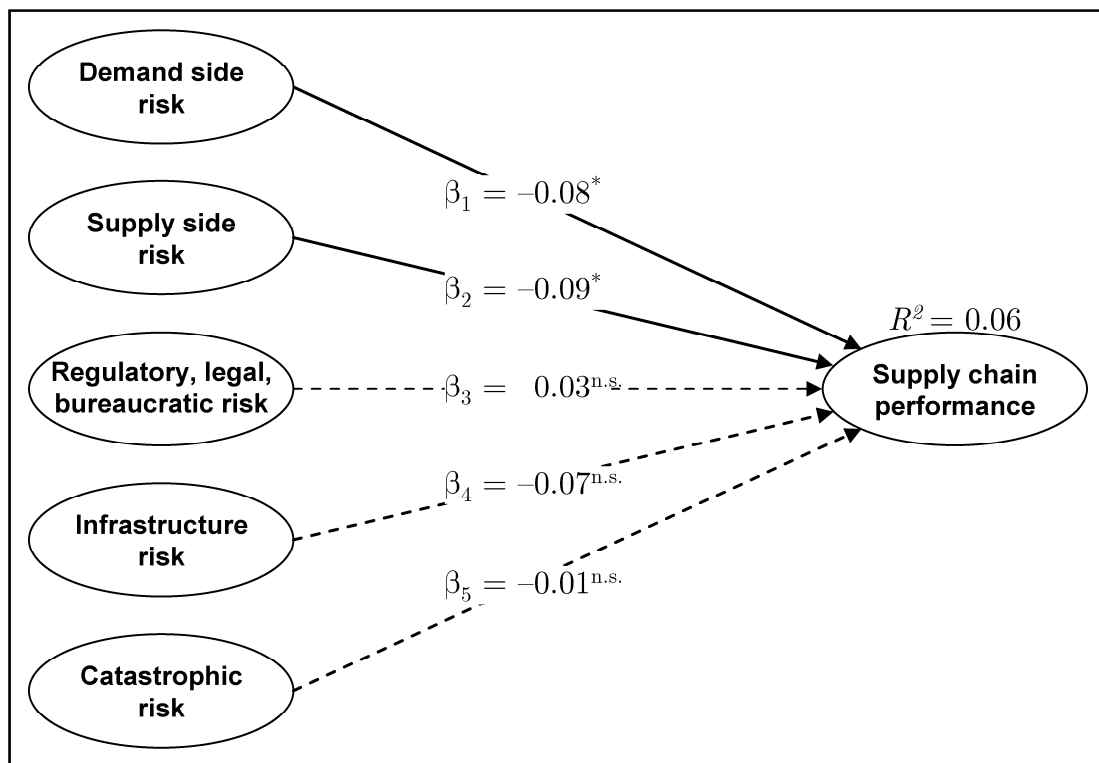
Table 12: Results of model estimation II (OLS regression)

Independent variables	β	t -value	p -value	Hypothesiz. relationship	Result
Predictor variables					
Demand side risk (DSR)	-0.08	1.98*	0.048	H ₁ ^{II} : positive	Support
Supply side risk (SSR)	-0.09	1.99*	0.047	H ₂ ^{II} : positive	Support
Regulatory, legal, and bureaucratic risk (BUR)	0.03	0.61	0.564	H ₃ ^{II} : positive	No support
Infrastructure risk (IFR)	-0.07	1.57	0.118	H ₄ ^{II} : positive	No support
Catastrophic risk (CTR)	-0.01	0.33	0.743	H ₅ ^{II} : positive	No support
Control variable					
Risk management (SCR)	0.18	4.75**	0.000	–	–
Model summary: $R^2 = 0.06$; $F_{(6, 688)} = 6.96^{**}$					

Note. β refers to standardized OLS regression estimates. f^2 refers to effect size. Absolute t -values are shown.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ (one-tailed).

Table 12 reports the results of the regression analysis with standardized parameter estimates and the t -values. Figure 12 depicts the results of the estimated model. Post hoc statistical power analysis ($\alpha = 0.001$) for the regression showed sufficient statistical power of $1 - \beta = 0.995$ which provides support that the regression is adequate to detect the hypothesized effects (Cohen et al., 2003).



Note. For purpose of clarity, control variable *supply chain risk management* as well as measurement items are excluded.

Figure 12: Results of model estimation II

The supply chain risks explained 6% of the variance of supply chain performance ($F = 6.96, p < 0.01$). H_1^{II} posits a relationship between demand side risk and supply chain performance. With a standardized parameter estimate of $\beta_1 = -0.08$, this hypothesis was significant ($t = -1.98, p < 0.05$), indicating support for H_1^{II} . H_2^{II} , that supply side risks have a negative impact on supply chain performance, was also supported with a statistically significant estimate of $\beta_2 = -0.09$ ($t = -1.99, p < 0.05$). However, for the effect of regulatory, legal, and bureaucratic risks, infrastructure risks, and catastrophic risks on supply chain performance, as proposed in H_3^{II} , H_4^{II} , and H_5^{II} , the data did not reveal statistically significant relationships. Therefore, H_3^{II} , H_4^{II} , and H_5^{II} , were not supported.

4 Discussion

Based on a sample of 760 top-level executives in logistics and supply chain management (Study 1), the results shed important light on the relationship between supply chain risks and supply chain performance and the relevance of supply chain risk sources as contextual variables in supply chain decision making.

Supply chain risk only partially explains the variance in supply chain performance. In particular, there is no significant relationship between regulatory, legal, and bureaucratic risks, infrastructure risks, and catastrophic risks and supply chain performance. The rather low R^2 is not astonishing since a firm's supply chain performance is clearly dependent on many factors other than supply chain risks. With regard to the last two risk sources, disruptions from these classes are, in general, outliers or exceptional events that are characterized by a low probability of occurrence (Stauffer, 2003). Therefore, an obvious explanation is that their probability is low enough to have a negligible impact on supply chain performance. In sum, authority actions, potential infrastructure disruptions, and catastrophes are not contextual variables that must necessarily be factored into strategic supply chain decisions (Mintzberg et al., 1976; Pettigrew and Whipp, 1993).

This seems counterintuitive in light of the intense interest of practitioners and academics to understand and manage the sources of supply chain risks. However, there is a widely accepted psychological rationale for the overestimation of the impact of supply chain disruptions in general and the hypothesized but non-significant relationships between the three risk sources and supply chain performance in particular. Research by psychologists has shown that people, instead of using statistics, rely on a limited number of heuristics to predict the impact of risks. These heuristics sometimes result in reasonable judgments and sometimes in serious errors (Kahneman and Tversky, 1973). One such heuristic is the *availability heuristic* (Slovic, Fischhoff, and Lichtenstein, 1982). Human beings make judgments based on what they can remember, not on complete data. This heuristic is

commonly used for judging the frequency or likelihood of events, such as supply chain risk sources (e.g., supply chain disruptions caused by floods).

News coverage also has a significant effect on decisions. After a news feature about a fire in a manufacturing plant or an airport evacuation in the wake of a bomb threat, managers will be more aware of the impact of such events on their firm's supply chains. Other factors can also affect managers' judgment. Things which are easier to imagine, for example, are more available. It is easier for people to remember images of flooded harbors, empty airports and autoworkers on picket lines than the lack of communication with suppliers and/or customers. The attention that these events receive is much higher than they merit according to their probability (Stauffer, 2003).

The conclusion that supply chain risks do not have a large effect on supply chain performance needs to be contrasted with the findings of Hendricks and Singhal (2003; 2005a; 2005b). As described in Chapter 1 in the delineation of Research Question II, Hendricks and Singhal analyzed the impact of announcements of supply chain disruptions on shareholder value and operating performance and show that both performance measures are substantially affected by supply chain disruptions. A careful examination and comparison of their study and the results presented in this chapter reveals that both approaches differ strongly and that the results do not contradict each other. Hendricks and Singhal's work was based on a completely different sample and measured a different issue. The observation of ad-hoc announcements yields two things: major supply chain disruptions (minor disruptions or problems are not announced in the media) and firms that were really affected by such a major supply chain disruptions. Apart from the shortcomings of the applied event-study methodology (MacKinlay, 1997; McWilliams and Siegel, 1997), their sample is biased in favor of large supply chain disruptions. They study *if-then* situations where "risk has already struck" which sheds, undoubtedly important, light on the question how supply chain disruptions

affect shareholder value and operational performance *under the condition* that a massive disruption has already occurred.

The sample used here is randomly drawn from a population and therefore includes both firms that may have been confronted with supply chain disruptions and firms that have not endured such a problem, or only a minor one. Therefore, these results indirectly acknowledge the frequency of supply chain disruptions experienced by the firms. In other words, the obtained results shed light on the importance of supply chain risk sources as a contextual variable in strategic decisions. Additionally, this research is not restricted to major supply chain risks that are publicly reported: it is also sensitive to minor supply chain risks. Finally, this research focuses on supply chain performance which is not in a direct relationship with share price or shareholder value.

Having illustrated that certain supply chain risks are less relevant as context in the strategic decision making of German firms, it is certainly more important for strategists and managers to understand which supply chain risk sources they should consider. The findings reveal relationships between supply and demand side risks and supply chain performance. Hence, supply and demand side risks are contextual variables that supply chain strategies need to take into account (Mintzberg et al., 1976; Pettigrew and Whipp, 1993). This finding is consistent with the literature on supply chain management. Primarily, it supports the assumption that supply and demand coordination is the central issue in supply chain management (Kleindorfer and van Wassenhove, 2004).

5 Managerial and research implications

The objective of this research was to examine the relevance of various supply chain risk sources for strategic decision making based on the relationship between supply chain risks and supply chain performance.

The findings support the assumption that there are negative associations between supply and demand side risks and supply chain performance; in other words, that these risk sources are relevant contextual variables in strategic supply chain decisions. However, the results relativize the current impassionate discussion of the subject. In terms of regulatory, legal, and bureaucratic risks, infrastructure risks and catastrophic risks, the study yields no empirical support for a negative relationship with supply chain performance. Overall, the data reveal a significant, but rather low impact of supply chain risks experienced by firms operating in Germany on supply chain performance.

A consequential next step would be an empirical study of supply chain performance based on the strategy process and the strategy content while taking supply chain risk into account as context would be highly interesting (Ketchen et al., 1996). As presented in Chapter 1, previous conceptual and qualitative research has focused on the strategy content, i.e., provides insights into a large set of supply chain risk management strategies. Some discuss operational risks (Johnson, 2001), others examine disruption risks (e.g., Kleindorfer and Saad, 2005; Lee and Wolfe, 2003; Sheffi, 2001) and still others provide general guidelines (e.g., Chopra and Sodhi, 2004; Christopher and Peck, 2004; Craighead et al., 2007; Rice and Caniato, 2003; Zsidisin et al., 2005b). However, the influence of these strategies on the relationship between supply chain risk and supply chain performance has neither been thoroughly underpinned with theory nor analyzed through empirical research. In this respect, many additional questions are still open.

Several managerial implications can be deduced from this study. First, supply chain risks have a negative impact on supply chain performance. As a consequence, they underscore the importance of supply chain risk management concepts and measures. Second, while Hendricks and Singhal (2003; 2005a; 2005b) showed that severe disruptions have substantial negative consequences on the health of the affected firms, the findings of this research take into consideration the frequency of occurrence of those effects. Given that severe disruptions (e.g., caused

by regulatory, legal or bureaucratic barriers, infrastructure breakdowns, or serious catastrophes) which lead to the release of ad-hoc announcements occur less frequently than every-day demand side and supply side disruptions, these latter risk sources are in fact very important for achieving high supply chain performance. Thus, decision makers should turn their attention to these two risk sources. Third, supply chain managers should bear in mind an acceptable cost-benefit trade-off in their firms' mitigation endeavors concerning major contingency risks (Sarathy, 2006). In support of a better utilization of risk management resources, the results advocate the allocation of scarce resources to the mitigation of demand side and supply side risks. This aspect ties in with the introduction in Chapter 1 which depicted how the series of recent catastrophes has intensified the attention to supply chain risk management.

Chapter 4 Organizational responses to supply chain disruptions

Based on the data gathered in Study 2, this chapter investigates buying firms' reactions to supply chain disruptions. In essence, two strategic approaches that a firm may pursue in the aftermath of a supply chain disruption are outlined and tested: *buffering* and *bridging* (e.g., Scott and Davis, 2007). *Buffering* is an attempt to *reduce* risk by establishing safeguards that protect the firm's technical core from environmental turbulence. In contrast, *bridging* is an attempt to *manage* vulnerabilities through boundary-spanning and boundary-shifting actions with exchange partners in the task environment, such as suppliers. The ideas posited in this research have support from the organizational crisis literature (in a supply chain context), from resource dependence theory, as well as from the organizational learning and culture literature.

In this chapter, the focus is restricted to supply chain disruptions where the triggering event materialized in the upstream supply chain (the supply network), in the inbound logistics network, or in the purchasing environment. Hence, supply chain disruptions from the supply side risk source are examined.

The following section reviews the literature and explores the development of several empirically testable hypotheses, which may be found in Section 2. Section 3 discusses the research methodology. Section 4 presents the results for the measurement and structural model. Sections 5 and 6 discuss the results from the scholarly and managerial perspectives, respectively. The paper concludes by describing the limitations of the study and by making recommendations for future research.

1 Theoretical background

1.1 The stages of a supply chain disruption

There are multiple frameworks for understanding how an organizational crisis unfolds (e.g., Fink, 1986; Shrivastava, Mitroff, Miller, and Miglani, 1988; Turner, 1976). According to Fink's (1986) four-stage process model, which is adopted for this research's view on supply chain disruptions, a supply chain disruption begins with the (I) *prodromal stage* in which early warning signals (e.g., a supplier's bad credit rating) might foreshadow a serious adverse event. Then, a triggering event (e.g., the supplier's sudden financial default) sets off the (II) *acute (or emergency) stage* that creates loss and often involves uncertainty, stress, limited or fragmented information, and demands swift decision making (Billings et al., 1980). During the (III) *chronic stage*, the firm recovers from the disruption and evaluates its direct reaction to it (i.e., the operative decisions and actions, during the heat of the acute stage). Subsequently, the firm returns to "business as usual" in the (IV) *resolution stage* during which it makes the decision to tactically (short- and mid-term) or strategically (long-term) respond to the supply chain disruption (Meyer, 1982). The literature examining this final stage in the context of supply chain disruptions is limited. Primo, Dooley, and Rungtusanatham (2007) explored the factors that affect a manufacturing firm's dissatisfaction with a supplier after the occurrence of a supply chain disruption and found that this dissatisfaction increases with the impact of the disruption. From a marketing perspective, Grewal, Johnson, and Sarker (2007) investigated the consequences of a supply chain disruption on a firm's relationships with customers and suppliers. Their exploratory findings suggested that the inter-organizational relationship climate (trust, commitment, and cooperation) was crucial for the successful resolution of the disruption.

1.2 Organizational learning

Organizational adaptation and learning have been examined from a wide variety of theoretical perspectives (for a review, see Argote, 1999), one of them being the experience-based learning perspective, which holds that organizational learning is a process of gathering experience and drawing inferences from this historical experience in repositories of organizational knowledge for future actions (Cyert and March, 1963; Levitt and March, 1988). At its most basic level, learning creates the potential for behavioral change (Huber, 1991). Organizational learning can occur from (1) repetitive experience and (2) rare experience. Organizational learning from repeated experience has been intensively investigated. A well-known example of repetition-based learning is the learning curve concept which states that the cost per unit produced decreases with the cumulative number of units produced (Wright, 1936; Yelle, 1979). Since supply chain disruptions usually represent rare or even novel experiences, the findings from this research stream may seem hardly applicable to the context of supply chain disruptions.

At the same time, much of the literature on organizational learning has recognized that infrequent, hazardous experiences can be a valuable source of organizational learning and, as a consequence, the source of competitive advantage (e.g., Hurst, 1995; Nathan and Kovoov-Misra, 2002; Sitkin, 1992). Sitkin (1992) emphasized the “transformational nature” of failure and unanticipated external challenges. Particularly higher-level learning (i.e., more drastic changes of overall rules, norms, strategies, or structures with a long-term impact) often needs an extreme external stimulus (Fiol and Lyles, 1985). This stems from the idea that sudden hazardous environmental events force an organization to question existing schemes and structures and to unlearn habitual behaviors (Hedberg, 1981; Nystrom and Starbuck, 1984). Moreover, such events seem to open a window of opportunity during which organizational inertia can be overcome (Carley and Harrald, 1997; Meyer, 1982). Along the same lines, Schein (2004) described organizational crises as unfreezing events, because they create the anxiety within the organization which

motivates it to give up a rigid adherence to its customary behavior. This sense of urgency may also precipitate external stakeholders' cooperation and support (Seeger, Ulmer, Novak, and Sellnow, 2005).

1.3 Buffering and bridging strategies

The open systems perspective suggests that a firm is never self-sufficient and, in order to survive and to function, it must enter into exchange relationships with its task environment consisting of competitors, suppliers, and customers having direct transactions with the organization (Dill, 1958; Katz and Kahn, 1978). In general, there are two possible actions a firm may take to manage these relationships and to cope with environmental turbulence: *buffering* and *bridging* (Fennell and Alexander, 1987; Katz and Kahn, 1978; Meznar and Douglas, 1995; Scott and Davis, 2007). Both approaches seek organizational stability and attempt to enhance the security of the organization vis-à-vis its task environment. They are applicable at several organizational levels and in varying degrees (Lynn, 2005).

The strategy of *buffering* aims at *reducing* or *eliminating* the firm's external resource dependencies and at achieving higher levels of autonomy (Galbraith, 1973; Thompson, 1967). A buffer insulates an organization from the exchange relationships and mitigates the detrimental consequences of external disturbances. First, a common approach to safeguard against the consequences of a sudden shortfall in supply is the diversification of the supply base by installing multiple redundant suppliers (Anupindi and Akella, 1993). Second, a firm can build up slack (i.e., inventory, flexibility, or time buffers), which acts as "shock absorber" (Bourgeois, 1981). Third, final products can be modularized and components standardized; this also supports a firm in becoming more tolerant of external uncertainties (Tang, 2006a).

The strategy of *bridging* aims at *managing* the external resource dependencies by improving the relationships with the external exchange partners or

by enlarging the control and influence over them (Aldrich, 1979; Katz and Kahn, 1978). In contrast to buffering, bridging encompasses actions that directly alter or strengthen the existing exchange relationships. To create a “bridge” between themselves and their exchange partners, firms can modify their relationships more or less drastically or formally, ranging from forming links with influential individuals in supplier firms to vertical integration (Ulrich and Barney, 1984). Other options are to establish contracts with suppliers in order to ensure their compliance and incorporation in the decision making process. Bridging may also imply environmental scanning which includes such actions as monitoring of exchange partners and enhancing the inter-organizational information exchange (Pfeffer and Salancik, 1978; Scott and Davis, 2007). Not only do these actions reduce uncertainty, they also enable the firm to detect early warning signals about critical environmental changes and to develop adequate and prompt responses.

2 Model development and hypotheses

In order to test a hypothesized model that attempts to explain the focal firm’s direct response to a disruption during the *resolution stage* (IV), this research includes respondents (focal firms) that experienced a supply chain disruption in which a specific supplier was significantly involved.

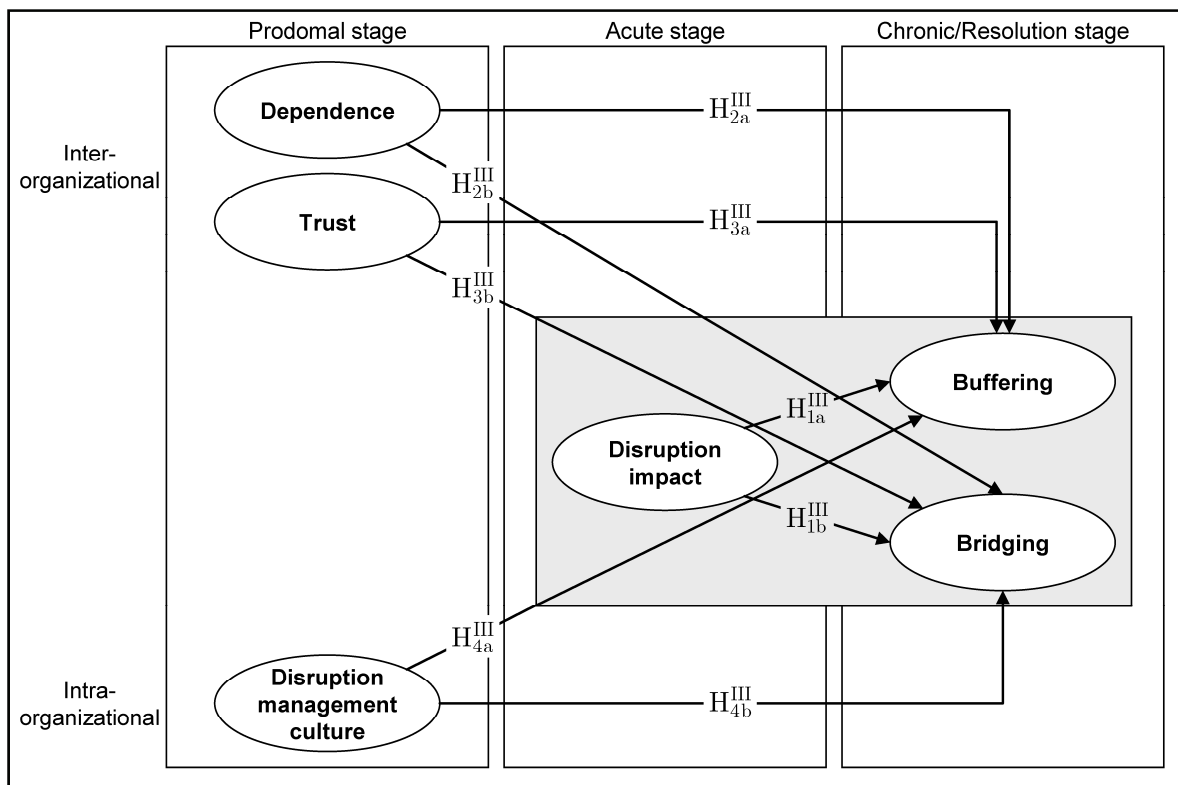


Figure 13: Conceptual framework III

Figure 13 depicts the posited model and the relationships that will be developed. This model is built on two bodies of knowledge. First, it is suggested that supply chain disruptions elicit adaptive responses as they erode the legitimacy of the existing state by exposing its vulnerability to the decision makers (Greenwood and Hinings, 1996; Meyer, 1982). The experience-based learning perspective provides the theoretical underpinning for this reasoning. When examined from this perspective, a supply chain disruption can expose flaws and vulnerabilities in the supplier or the buyer-supplier relationship. The focal firm then draws inferences from this lesson in crafting its response (Meyer, 1982; Turner, 1976). The stimulus for these processes of change and adaptation is provided by the exceptional and “painful” circumstances of the supply chain disruption (Nathan and Kovoov-Misra, 2002; Schein, 2004).

Second, resource dependence theory is employed to conceptualize the focal firm’s response regarding the dyadic relationship with the involved supplier.

Strongly rooted in both open systems perspective (Katz and Kahn, 1978) and social exchange theory (Blau, 1964; Homans, 1958; Thibaut and Kelley, 1959), resource dependence theory explains how organizations manage and react to the relationships with their task environment (Pfeffer and Salancik, 1978). The premise of this theory is that the organization's essential need for scarce external resources creates dependence on exchange partners, resulting in potential sources of adversity and vulnerability. As any organization strives to minimize dependence, which is tantamount to maximizing power (Pfeffer, 1981), coping with problematic exchange relationships and their accompanying vulnerabilities is crucial. It can be argued that, in response to the supply chain disruption, the focal firm will strive to reduce or manage the vulnerability experienced and resource dependence by following the strategies of buffering and/or bridging. Buffering is a defensive approach aimed at creating internal tolerance while bridging is an offensive approach employing closer working relationships with the suppliers, including collaboration. In the short- and mid-term time planning horizons, both strategies are largely independent of each other (Scott and Davis, 2007).

2.1 Disruption impact

The impact of the supply chain disruption reflects a deficiency in safeguarding against the uncertainties in the supply network. Drawing from the experience-based learning perspective, the supply chain disruption pushes a firm over a threshold of resistance so that it can learn from its mistakes (Jackson and Dutton, 1988). The disruption provides the stimulus for a process of inquiry aimed at improving a state that had previously been considered acceptable (Greening and Gray, 1994; Meyer, 1982). The intensity of this stimulus increases with the severity of the supply chain disruption. Hence, the increasing severity of a supply chain disruption is paralleled by an increasing urgency to address the exposed vulnerabilities and to question behaviors, routines, and exchange relationships within the task environment (Hedberg, 1981). In addition, the pressure for action created by the firm's internal

and external stakeholders increases (Schein, 2004; Seeger et al., 2005). This sense of urgency is fueled by the decision makers' fear of a similar supply chain disruption in the future. It can be expected that more serious supply chain disruptions to be associated with more dramatic organizational responses. Therefore,

Hypothesis H_{1a}^{III}: *The severity of the experienced supply chain disruption is positively related to the pursuit of buffering.*

Hypothesis H_{1b}^{III}: *The severity of the experienced supply chain disruption is positively related to the pursuit of bridging.*

2.2 Dependence on the supplier

At the heart of resource dependence, Emerson (1962) suggested that a given entity A is dependent on entity B to the extent that B controls some resource valued by A and that A cannot obtain this resource from alternative entities. Emerson also concluded that dependence is implicitly the opposite of power. That is, if the focal firm is dependent on the supplier, the supplier has power over the focal firm. For this reason, dependence has been traditionally considered to be a liability (Gaski, 1984). Dependence on the supplier places constraints on the focal firm's ability to alter or replace the dysfunctional relationship (Buchanan, 1992). Especially in the short run, a high level of dependence on the supplier implies that the "captive" firm is forced to accept the locked-in relationship, because of its incapacity to change the current situation (Bourantas, 1989; Caniëls and Gelderman, 2005). Given that the buffering option is temporary unavailable, the supply chain disruption will push the focal firm to invest in the relationship in order to gain resilience. In addition, bridging may be preferable in settings in which there is a high level of uncertainty associated with the inter-organizational dependence (Scott and Davis, 2007). It can be expected that if the focal firm is relatively dependent on the specific supplier, the

buying firm will seek stability by investing in the exchange relationship instead of buffering it. Therefore,

Hypothesis H_{2a}^{III}: *The buying firm's dependence on the supplier is negatively related to the pursuit of buffering.*

Hypothesis H_{2b}^{III}: *The buying firm's dependence on the supplier is positively related to the pursuit of bridging.*

2.3 Trust in the supplier

One of the core assumptions of resource dependence theory is that the social context is of critical importance for the way firms manage and react to their environment. Therefore, various authors have made a strong case to consider social constructs, particularly trust, in exchange relationships as a complement to resource dependence theory (Andaleeb, 1996; Casciaro and Piskorski, 2005). Inter-organizational trust is a key relational norm and instrumental in explaining the development of exchange relationships (Anderson and Weitz, 1989; Dwyer, Schurr, and Oh, 1987; Morgan and Hunt, 1994). Grewal, Johnson, and Sarker (2007) suggested that trust is a central factor in the successful resolution of supply chain disruptions in buyer-supplier relationships. Trust mitigates uncertainty about partner behavior and has been conceptualized as the willingness to rely on another party and to take action in circumstances where such action makes one vulnerable to the other party. Stable exchange relationships develop through the presence of trust, because trust reduces the risk of opportunistic behavior, lowers transaction costs, and supports the development of a long-term orientation (Anderson and Weitz, 1989; Ganesan, 1994). Thus, a focal firm that has great trust in its supplier should have a lower propensity to buffer the relationship, because the trust implies that the firm has confidence in the supplier's ability to fulfill its obligations and not to exploit vulnerabilities (Anderson and Narus, 1990; Mayer, Davis, and Schoorman, 1995; Morgan and Hunt, 1994). At the same time, it can be expected that the focal

firm has a higher propensity to pursue bridging strategies subsequent to the supply chain disruption if it trusts the supplier. Thus,

Hypothesis H_{3a}^{III}: *Trust in the supplier is negatively related to the pursuit of buffering.*

Hypothesis H_{3a}^{III}: *Trust in the supplier is positively related to the pursuit of bridging.*

2.4 Disruption management culture

Within organizational learning theory, an organizational culture is a deeply rooted set of shared assumptions, beliefs, and values (Deshpandé and Webster, 1989). This culture provides norms for behavior and for common practice in the organization. In the context of the organizational response to supply chain disruptions, this study contends that organizational culture is an important factor.

First, organizational culture has been reported to be the primary source of resistance to change and learning (Argyris, 1990; Lant and Mezias, 1990). Hofmann and Stetzer (1998) investigated how safety climate, conceptualized as the employees' shared perceptions about the importance of safety, influences an organization's interpretation of information about an adverse event. Consistent with other studies (e.g., Edmondson, 1996; March, Sproull, and Tamuz, 1991), they conjectured that in order for organizational learning (prompted by a negative event) to occur, communication about the event must be open, positive, and free-flowing.

Second, organizational culture is a major consideration in organizational crisis resolution and response (Grabowski and Roberts, 1996). The organizational culture frames and influences the interpretation of information. This is highly relevant for the decision making and response-crafting processes during the acute and chronic stages of a supply chain disruption. Schein (2004) stated that "the nature of that response will reflect deep elements of the culture" (p. 107).

Third, according to high reliability theory (e.g., Roberts, 1990; Roberts, Stout, and Halpern, 1994; Weick, 1987), organizational culture of firms that are exceptionally proficient in dealing with unexpected events is marked by a zeal to learn from these negative events (preoccupation with failure), blame-free and open communication about errors, continuous improvement processes, and training of employees to recognize and respond to system abnormalities (Roberts and Bea, 2001).

Drawing from research on high reliability organizations and their culture, this study proposes that disruption management culture features (1) preoccupation with supply chain disruptions, (2) sensitivity to operations, (3) commitment to resilience, and (4) a continuous improvement process. It can be expected that a strongly pronounced disruption management culture leads to a prompt and sensitive response to supply chain disruptions. Thus,

Hypothesis H_{4a}^{III}: *A disruption management culture is positively related to the pursuit of buffering.*

Hypothesis H_{4a}^{III}: *A disruption management culture is positively related to the pursuit of bridging.*

3 Methodology

3.1 Data and procedure

The unit of analysis in this survey is a supply chain disruption as conceptualized in Section 2.2 of Chapter 1. Respondents were asked to base their answers on a specific supply chain disruption that had occurred during the twelve months preceding the data collection and in which a specific supplier was involved – but for which it was not necessarily entirely responsible.

Table 13: Sample supply chain disruptions

Date	Description	Purchased item	Location of triggering event	Disruption impact ^a
Oct-2006	“Supplier was bought by a larger company and no longer able to provide previous products to us.”	Unit, module, or component	USA	3.00
Dec-2006	“Sub supplier terminated a critical series of raw materials that are unique to certain equipment.”	Raw material	Germany	2.17
Jul-2007	“Allocation of raw material prevented supplier from receiving usual monthly allotment.”	Raw material	Canada	3.67
Aug-2007	“Transition of a key supplier’s manufacturing from one plant to another caused several shortages and unexpected increases in lead-time.”	Unit, module, or component	USA	2.83
Sep-2007	“Delay in clearing of customs of a sea container carrying important production parts.”	Unit, module, or component	Czech Republic	4.83

^aMean of all scores from the six-item measure *disruption impact* (see Table 15).

Table 13 provides a selection of the reported disruptions described by respondents, highlighting the broad variety of disruptions reported.

3.2 Measures

The development of the survey instrument and the measures consisted of several stages. For the constructs *dependence* on and *trust* in the supplier, multi-item scales were adopted that had been previously utilized in supply chain management research. In both cases, to enhance translation equivalence, one person translated the original English items into German and a second person translated these items back into English (Brislin, 1970). Any differences between the two versions were reconciled by the two expert translators. For the remaining constructs (*disruption impact*, *disruption management culture*, *buffering*, and *bridging*), it was necessary to develop new multi-item scales as no suitable measures were found. To this end, standard psychometric scale development techniques were followed to ensure content validity (Churchill, 1979; DeVellis, 2003). This process included several preliminary qualitative interviews with purchasing managers, an extensive review of the extant academic and practitioner literature, in-person pretesting, as well as a small pretest study.

Table 14: Measures of constructs III

Construct name/Item (response cue)	Number of items	M	SD
Disruption impact (IMP)	5	2.65	0.82
<i>How did the disruption negatively affect (directly or indirectly) your business unit on the following dimensions in the short-run? (1: not at all – 5: to a very large extent)</i>			
IMP2 Overall efficiency of our operations		3.15	1.20
IMP3 Product quality of our final product(s)		2.22	1.32
IMP5 Delivery reliability (on-time delivery, order accuracy)		3.61	1.30
IMP6 Access to technology		1.66	0.92
IMP7 Sales		2.51	1.21
IMP8 Return on sales		2.74	1.25
Dependence (DEP)	4	3.72	1.01
<i>Please indicate your opinion on the following statements referring to the relationship with this supplier (1: strongly disagree – 5: strongly agree)</i>			
DEP1 If our relationship with this supplier had been discontinued, we would have had difficulty achieving our goals.		3.91	1.10
DEP2 It would have been difficult for us to replace this supplier.		3.79	1.12
DEP3 We were quite dependent on this supplier.		3.68	1.16
DEP4 We did not have a good alternative to this supplier.		3.51	1.23
Trust (TRU)	5	3.61	0.72
<i>Please indicate your opinion on the following statements referring to the relationship with this supplier (1: strongly disagree – 5: strongly agree)</i>			
TRU1 This supplier kept the promises it made to us.		3.33	0.94
TRU2 This supplier was always honest with us.		3.49	0.95
TRU3 We were confident in the information that this supplier provided us.		3.73	0.81
TRU4 This supplier was trustworthy.		3.76	0.82
TRU6 When making important decisions, this supplier considered our welfare as well as its own.		3.72	0.89
Disruption management culture (CUL)	5	4.00	0.60
<i>Please indicate your opinion on the following statements referring to your business unit (1: strongly disagree – 5: strongly agree)</i>			
CUL1 We feel the need to be alert for possible supply chain disruptions at all times.		4.09	0.82
CUL2 Supply chain disruptions show us where we can improve.		3.88	0.93
CUL3 We recognize that supply chain disruptions are always looming.		4.30	0.69
CUL4 We think a lot about how a supply chain disruption could have been avoided.		3.94	0.87
CUL5 After a supply chain disruption has occurred, it is analyzed thoroughly.		3.77	0.96
Buffering (BUF)	3	3.2	0.93
<i>Since the disruption, to what extent has your business unit pursued, or made plans to pursue, the following activities? (1: not at all – 5: to a very large extent)</i>			
BUF1 Make us more independent of this supplier or the purchased item.		3.04	1.24
BUF2 Increase our protective barriers against disturbances in the supply of the purchased item.		3.18	0.99
BUF4 Search for or develop one or more alternative supplier(s) for the purchased item.		3.37	1.28
Bridging (BRI)	5	3.06	0.95
<i>Since the disruption, to what extent has your business unit pursued, or made plans to pursue, the following activities? (1: not at all – 5: to a very large extent)</i>			
BRI1 Establish a closer relationship with this supplier in order to collaborate better in case of supply chain disruptions.		3.01	1.14
BRI2 Tighten the control mechanisms on this supplier (e.g., more monitoring).		3.28	1.16
BRI3 Cooperate more intensively with this supplier.		3.06	1.14
BRI4 Improve information exchange with this supplier.		3.29	1.08
BRI5 Engage in risk management activities with this supplier (e.g., development of joint contingency plans).		2.67	1.18

Note. All items were measured on five-point rating scales (Likert-type). The construct mean is calculated as arithmetic mean of all scale scores.

Summated five-point rating scales (Likert-type) were used to operationalize all constructs with at least five items per scale. All items were formulated as indirect, reflective indicators and scored so that higher numbers reflect increases in the underlying constructs. Translations of the final measurement items, after their refinement with data from the survey, appear in Table 14.

Buffering and bridging were measured along the activities the affected focal firm pursued or intended to pursue in response to the experienced supply chain disruption. These activities were derived from the extant literature (e.g., Scott and Davis, 2007) and from the preliminary interviews with purchasing managers. *Buffering* was measured with items reflecting the activities of insulating the firm from the task environment. *Bridging* was measured with items reflecting collaborative supply chain initiatives, improved information exchange, and stricter monitoring of the supplier.

Supply chain *disruption impact* measured the extent to which the supply chain disruption had a negative direct or indirect effect on the focal firm. A supply chain disruption can have a variety of negative outcomes, such as loss of revenues, poor asset utilization, inventory management problems (write-offs, stock-outs), or damage to reputation and credibility. In order to reflect this multifaceted nature, the developed scale relates to the production process (efficiency of operations, quality of final products), the customers (delivery reliability), and the financial performance (sales, return on sales).

The firm's *dependence* on the supplier that was involved in the supply chain disruption was measured by a scale developed and validated by Jap and Ganesan (2000). This scale assesses the buying firm's inability to replace the supplier, to find an alternative supplier, and to achieve its goals in the event that the relationship is terminated.

The operationalization of *trust* in the supplier is based on the definition that views trust as a belief, sentiment, or expectation that the supplier is credible and

benevolent (Ganesan, 1994; Kumar, Scheer, and Steenkamp, 1995; Morgan and Hunt, 1994). Credibility implies that the partner is honest, effective, and reliable; benevolence implies that the partner is interested in the buying firm's best interest. A scale was adopted which was developed and validated by Doney and Cannon (1997). As Doney and Cannon (1997) did not find any evidence of discriminant validity in terms of trust in credibility and trust in benevolence, this study also treated trust as a first-order construct. Drawing from insights from the pretests, recoding of the reverse-coded items was necessary.

A new scale was developed for *disruption management culture*. This new scale leverages measurement items adapted from organizational error management culture (van Dyck, Frese, Baer, and Sonnentag, 2005) and climate for initiative (Baer and Frese, 2003). The adopted items along with newly developed items reflect the zeal to learn from supply chain disruptions and a state of permanent alertness and lively awareness.

4 Statistical analysis and results

The Anderson and Gerbing "two-step" approach was followed which requires the evaluation of the measurement models before estimating the hypothesized structural model (Anderson and Gerbing, 1988). In both steps, structural equation modeling was performed using EQS 6.1 (Bentler, 1995) with the covariance matrix as input to the model. Prior to this, missing data analysis indicated that the small amount of missing data (less than 2% of the total data points) was missing at random (MAR). Therefore, the Expectation-Maximization (EM) algorithm was applied to impute the missing values (Allison, 2001; Tsikriktsis, 2005).

4.1 Measure assessment

Confirmatory factor analysis (CFA) was used to validate the measures. To this end, all independent and dependent latent variables were included in a single

multifactorial CFA model. Given that some evidence of multivariate non-normality was found, this CFA model was estimated using the robust maximum likelihood estimation method (Curran et al., 1996).

Table 15: Factor analysis results and measurement statistics III

Construct/Item	Coefficient alpha	Total variance explained	Item- total reliability	Composite AVE	λ	t -value ^a	SE	IR
Disruption impact	0.76	0.63	0.75	0.53				
IMP2			0.45		0.54	9.35	0.09	0.50
IMP3			0.43		0.51	8.30	0.10	0.41
IMP5			0.52		0.64	9.72	0.10	0.56
IMP6			0.44		0.50	8.10	0.07	0.58
IMP7			0.60		0.65	13.68	0.07	0.60
IMP8			0.60		0.62	– ^b	– ^b	0.55
Dependence	0.90	0.77	0.90	0.84				
DEP1			0.72		0.79	19.10	0.05	0.83
DEP2			0.85		0.92	22.62	0.05	0.92
DEP3			0.80		0.84	– ^b	– ^b	0.87
DEP4			0.72		0.76	19.21	0.05	0.75
Trust	0.88	0.66	0.88	0.79				
TRU1			0.68		0.77	15.10	0.07	0.80
TRU2			0.80		0.88	17.28	0.07	0.89
TRU3			0.67		0.72	14.19	0.06	0.78
TRU4			0.78		0.83	– ^b	– ^b	0.88
TRU6			0.56		0.60	13.21	0.06	0.57
Disruption management culture	0.73	0.49	0.74	0.53				
CUL1			0.54		0.55	– ^b	– ^b	0.62
CUL2			0.41		0.49	7.66	0.11	0.37
CUL3			0.45		0.53	7.64	0.09	0.57
CUL4			0.60		0.73	10.46	0.11	0.65
CUL5			0.49		0.60	8.67	0.13	0.49
Buffering	0.69	0.62	0.76	0.59				
BUF1			0.66		0.97	– ^b	– ^b	0.56
BUF2			0.33		0.37	5.55	0.05	0.56
BUF4			0.57		0.67	7.27	0.09	0.65
Bridging	0.89	0.69	0.89	0.79				
BRI1			0.73		0.80	– ^b	– ^b	0.82
BRI2			0.66		0.70	15.48	0.06	0.69
BRI3			0.81		0.89	23.95	0.05	0.91
BRI4			0.81		0.87	20.39	0.05	0.91
BRI5			0.62		0.65	16.89	0.05	0.60

Note. All items were measured on five-point rating scales (Likert-type). λ refers to standardized factor loading, *SE* refers to standard error (asymptotically robust estimate), IR refers to indicator reliability.

See Appendix 2 for the list of items that were removed during the scale purification process.

^a t -values are from the unstandardized solution; All are significant at the $p < 0.001$ level (two-tailed).

^b Factor loading was fixed at 1.0 for identification purposes.

Based on common recommendations on fit statistics for models of comparable size (e.g., Hair et al., 2006), the measurement model showed an acceptable fit to the data: Satorra-Bentler-scaled $\chi^2/df = 2.33$ (SB-scaled $\chi^2_{(334)} = 776.70, p < 0.001$), CFI = 0.91, NNFI = 0.90, SRMR = 0.065, and RMSEA = 0.054 (90% confidence interval = [0.049, 0.059]). Details of the final measurement model appear in Table 15, and the inter-construct correlations and average variances extracted appear in Table 16 (inter-item correlations are shown in Appendix 5).

The CFA results indicate acceptable psychometric properties for all constructs showing that the reflective items used capture the respective underlying latent variables well and implying a satisfactory level of convergent validity and internal consistency. Without exception, each item loaded on its hypothesized factor with large, significant loadings, with all significant at the 1% level. Composite reliabilities and average variances extracted of all constructs exceed the common cut-off values of 0.70 (Nunnally and Bernstein, 1994) and 0.50 (Bagozzi and Yi, 1988; Fornell and Larcker, 1981). Discriminant validity was assessed on the basis of the criterion suggested by Fornell and Larcker (1981): as shown in Table 16, each construct extracts variance that is larger than the highest variance it shares with other constructs, thus providing support for discriminant validity.

Table 16: Inter-construct correlations and average variances extracted (AVE) III

	(1)	(2)	(3)	(4)	(5)	(6)
(1) Disruption impact	0.53	0.07	0.04	0.02	0.04	0.05
(2) Dependence	0.26**	0.84	0.00	0.05	0.00	0.10
(3) Trust	-0.19**	0.04	0.79	0.00	0.08	0.04
(4) Disruption management culture	0.13*	0.22*	0.06	0.53	0.06	0.15
(5) Buffering	0.21*	-0.04	-0.28**	0.24**	0.59	0.00
(6) Bridging	0.23**	0.31*	0.19**	0.39**	-0.03	0.79

Note. Diagonal values represent AVE values, squared correlations (shared variance) are in bold and above the diagonal, Pearson correlation coefficients are below the diagonal. For discriminant validity above-diagonal elements should be smaller than on-diagonal elements.

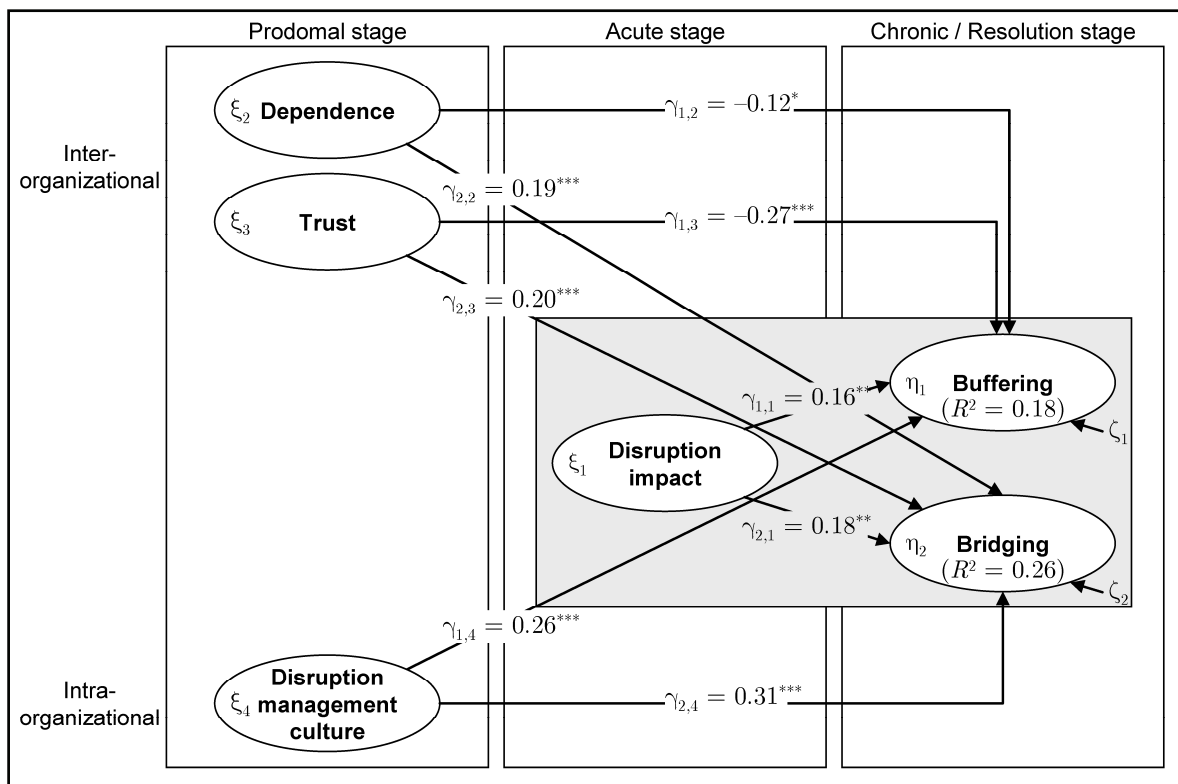
* $p < 0.05$, ** $p < 0.01$ (two-tailed).

Finally, addressing the potential concern of common method bias, Harman's one-factor test was applied (Podsakoff et al., 2003). To this end, all 28 items used in

the measurement models were subjected to a principal component factor analysis using the Kaiser-criterion (Kaiser, 1974) which yielded, as hypothesized, six factors with the first factor accounting for a proportion of 29.1% of the cumulative variance explained by the six factors (60.2%). This is substantially below the threshold of 50% proposed by Podsakoff and Organ (1986), thus suggesting the absence of a significant common method bias effect.

4.2 Structural model estimation and hypotheses testing

All structural relationships were assessed by simultaneously estimating the structural and measurement models. As for the CFA, the robust maximum likelihood estimation method was used.



Note. Completely standardized coefficients are shown. For purpose of clarity, measurement models and correlations between the exogenous variables ($\xi_1, \xi_2, \xi_3, \xi_4$) are excluded.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ (one-tailed).

Figure 14: Results of model estimation III

The fit statistics for the resulting structural model indicated an acceptable fit to the data: SB-scaled $\chi^2/df = 2.33$ (SB-scaled $\chi^2_{(335)} = 778.93$, $p < 0.001$), CFI = 0.91, NNFI = 0.90, SRMR = 0.065, and RMSEA = 0.054 (90% confidence interval = [0.049, 0.059]).

Figure 14 depicts the estimation results with standardized path coefficients and levels of significance. All path coefficient estimates were significant and in the expected direction. In total, the exogenous variables explained 18% of the variance in buffering and 26% of the variance in bridging.

Table 17: Results of model estimation III (SEM)

Direct effects		Estimate ^a	<i>t</i> -value ^b	<i>SE</i> ^b	Hypothesiz. relationship	Result
Disruption impact	→ Buffering	$\gamma_{1,1}$ 0.16	2.39 **	0.09	H _{1a} ^{III} : positive	Support
Disruption impact	→ Bridging	$\gamma_{2,1}$ 0.18	2.85 **	0.07	H _{1b} ^{III} : positive	Support
Dependence	→ Buffering	$\gamma_{1,2}$ -0.12	-2.05 *	0.07	H _{2a} ^{III} : negative	Support
Dependence	→ Bridging	$\gamma_{2,2}$ 0.19	3.49 ***	0.05	H _{2b} ^{III} : positive	Support
Trust	→ Buffering	$\gamma_{1,3}$ -0.27	-4.64 ***	0.09	H _{3a} ^{III} : negative	Support
Trust	→ Bridging	$\gamma_{2,3}$ 0.20	3.52 ***	0.08	H _{3b} ^{III} : positive	Support
Disruption management culture	→ Buffering	$\gamma_{1,4}$ 0.26	3.98 ***	0.13	H _{4a} ^{III} : positive	Support
Disruption management culture	→ Bridging	$\gamma_{2,4}$ 0.31	5.08 ***	0.11	H _{4b} ^{III} : positive	Support
Covariances among exogenous variables						
Dependence	↔ Disruption impact	$\phi_{2,1}$ 0.19	4.35 ***	0.04	–	–
Trust	↔ Disruption impact	$\phi_{3,1}$ -0.10	-3.10 **	0.03	–	–
Disruption management culture	↔ Disruption impact	$\phi_{4,1}$ 0.05	2.04 *	0.03	–	–
Trust	↔ Dependence	$\phi_{3,2}$ 0.03	0.82	0.03	–	–
Disruption management culture	↔ Dependence	$\phi_{4,2}$ 0.11	3.22 ***	0.03	–	–
Disruption management culture	↔ Trust	$\phi_{4,3}$ 0.02	0.91	0.02	–	–

^a Completely standardized estimates are from the robust maximum likelihood estimation method.

^b *t*-values and standard errors (*SE*) are from the unstandardized solution.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ (one-tailed).

Table 17 summarizes the results with regard to the developed hypotheses. The eight hypothesized relationships were found to be related in the theoretically predicted manner. In detail, the results support the two main hypotheses, i.e., the positive relationship between the supply chain disruption experience and the buying

firm's response in the form of buffering (Hypothesis H_{1a}^{III}) ($p < 0.01$) and bridging (Hypothesis H_{1b}^{III}) ($p < 0.01$). The magnitude of the two path coefficients ($\gamma_{1,1} = 0.16$ and $\gamma_{2,1} = 0.18$) was virtually equal, indicating that the disruption experience triggers the two response patterns in similar strength.

The remaining hypotheses refer to the inter- and intra-organizational antecedents of the organizational response. The second set of hypotheses asserts that the buying firm's dependence on the supplier is negatively related to buffering (Hypothesis H_{2a}^{III}) and positively associated with bridging (Hypothesis H_{2b}^{III}). The standardized effect of dependence on buffering was $\gamma_{1,2} = -0.12$ ($p < 0.05$) and on bridging $\gamma_{2,2} = 0.19$ ($p < 0.001$), supporting both Hypothesis H_{2a}^{III} and Hypothesis H_{2b}^{III}. Next, the two hypotheses pertaining to the focal firm's trust in the supplier, Hypothesis H_{3a}^{III} and Hypothesis H_{3b}^{III} were supported. The results show a strong tempering effect of trust on buffering ($\gamma_{1,3} = -0.27$, $p < 0.001$) and a strong enhancing effect of trust on bridging ($\gamma_{2,3} = 0.20$, $p < 0.001$). The fourth set of hypotheses asserts that a disruption management culture is positively related to buffering (Hypothesis H_{4a}^{III}) as well as to bridging (Hypothesis H_{4b}^{III}). Both hypotheses were supported with buffering ($\gamma_{1,4} = 0.26$, $p < 0.001$) and with bridging ($\gamma_{2,4} = 0.31$, $p < 0.001$).

5 Discussion

First, the core of the hypothesized model predicted that supply chain disruptions serve as a stimulus sufficient to overcome organizational inertia and to trigger activities seeking to minimize the vulnerability experienced in the future. The underlying idea behind this assertion relates to an important claim in theories of organizational learning that learning is triggered by adverse experiences and changes emanating from the task environment (Hedberg, 1981; Huber, 1991; Meyer, 1982). The results suggest that the concept of organizational learning provides significant explanatory power for the understanding of a firm's response to

supply chain disruptions. To date, supply chain disruptions have been viewed merely as threatening events that place firms in jeopardy. Yet this study refines this prevailing conceptualization of supply chain disruptions by showing that they can also lead to positive outcomes, stimulating learning and adaptation as firms attempt to ameliorate the impact of future potential disruptions. The deviation between the desired state and the current state during the acute stage of a supply chain disruption, which equals the perceived impact of the supply chain disruption (Billings et al., 1980), creates room for organizational learning. The obtained results support the hypothesis that the elicited organizational responses, which are taken to alleviate the experienced vulnerability, are proportional to the perceived impact of the disruption. Here, resource dependence theory and the derived conceptualization of the strategies of buffering and bridging drawn from the field of organizational research (e.g., Fennell and Alexander, 1987; Meznar and Douglas, 1995), were valid and insightful. In the aftermath of a supply chain disruption, some firms decide to change themselves (by buffering) while others decide to change the exchange relationships with the involved supplier (by bridging). However, as shown in Table 13, the limited correlation between buffering and bridging responses indicates that there is no (linear) relationship between them.

Second, the hypotheses pertaining to the two investigated inter-organizational aspects of dependence on and trust in the supplier were supported, suggesting that relationship issues play a critical role for the organizational response to supply chain disruptions. In the investigated setting, it was important to consider the effects of trust and dependence separately, because relations of dependence are not necessarily relations of trust (Andaleeb, 1996). In contrast, a dependent focal firm may not trust its supplier, but still maintains the relationship due to lack of alternatives or high switching costs. Consistent with the expectations and resource dependence theory, high reliance on the supplier imposes strong constraints on the response actions of the focal firm. With increasing dependence on the supplier, the pursuit of bridging activities increases while the pursuit of buffering activities

decreases. This is explained by the fact that dependent focal firms are bound by the constraints of maintaining and continuing the dyadic relationship in the short run subsequent to the supply chain disruption. Due to a lack of choice or high switching costs, the focal firm is forced to commit itself to the specific relationship by investing in it to reduce risk through improved supply chain disruption management capabilities or by stricter monitoring of the supplier. In such a setting, the desire to achieve resilience and to minimize vulnerability creates commitment in terms of the focal firm's intention to continue the relationship and willingness to make short-term sacrifices (Dwyer et al., 1987). This may even hold in cases where the supply chain disruption leads to increased relational conflict, such as dissatisfaction, blame, or anger, triggered by the belief that the supplier was responsible for the disruption. Arguably, the nature of this commitment is rather calculative, and triggered by rational and economic considerations. In contrast to affective commitment, calculative commitment has been reported to be precarious and short-lived (Brown, Lusch, and Nicholson, 1995; Gundlach, Achrol, and Mentzer, 1995).

Third, similar to the dependence on the supplier, increasing levels of trust in the supplier also lead to more bridging and fewer buffering activities. The critical role of trust in buyer-supplier relationships has often been highlighted in the literature (e.g., Morgan and Hunt, 1994). Trust exerts a significant influence on the behaviors and attitudes of the exchange partners with regard to their relationship. In the conceptual framework, the trust that has been established between the two exchange partners leads the focal firm to strengthen the relationship by engaging in bridging instead of buffering activities. This result is consistent with prior buyer-supplier relationship research that showed the relevance of trust for commitment, long-term orientation, and stability (Anderson and Weitz, 1989; Ganesan, 1994), defusing of conflict (Zaheer, McEvily, and Perrone, 1998), and propensity to collaborative exchange (e.g., Cannon and Perreault, 1999; Jap and Ganesan, 2000). The results here indicate that in the presence of trust in the relationship, the risk of pursuing bridging activities decreases for the focal firm, because it has experience-

based confidence that the collaboration with the supplier will result in a favorable outcome in terms of reduced supply chain vulnerability. The focal firm's confidence in the reliability, fairness, and integrity of the supplier makes the relationship robust during and after a supply chain disruption. Exchange continues due to the value inherent in trust. It is important to note that the findings of this study support the notion of "trust but verify," as tightening of control mechanisms on the supplier also loaded positively on the bridging construct.

Fourth, the developed model asserted that firms with a disruption management culture show an increased tendency to take action after a supply chain disruption by engaging in both buffering and bridging activities. The results support this view and send the general message that organizational culture has a significant influence on the way firms cope with supply chain disruptions. Based on a review of the extant literature on organizational learning and high reliability organizations, the concept of disruption management culture was introduced to the supply chain management context. The proposed conceptualization encompasses the initiative to improve flawed procedures, the thorough ex post analysis of supply chain disruptions, and the vigilant awareness that even though the supply chain system is well understood and under control, it can fail or be disrupted. The results suggest that such a culture makes firms more sensitive to supply chain disruptions, and more likely to craft and execute a specific response for reducing the likelihood and impact of future, similar disruptions. This is consistent with previous studies that emphasized the importance of organizational culture in enhancing a firm's capabilities of learning and dealing with adverse events (Edmondson, 1996; van Dyck et al., 2005). Moreover, prior research also supports the conclusion that quick and sensitive responses to environmental changes (agility) are linked to superior performance. For example, firms that radically and rapidly alter their formal structures, decision making routines, and information-processing approaches in response to changes in their task environment perform better over their lives than organizations that change gradually or incrementally (Miller and Friesen, 1982;

Virany, Tushman, and Romanelli, 1992). As a consequence, it can be argued that a strong disruption management culture represents a competitive advantage, which takes this discussion full circle and back to the “Albuquerque fire” example mentioned in Sections 2.4 and 3.3 of Chapter 1: Sheffi (2005, p. 8) analyzed this supply chain disruption in detail and concluded that Ericsson’s “friendly” organizational culture (in contrast to the more aggressive culture at Nokia) was an important factor in underestimating the supply chain disruption.

Finally, this study proposed, defined, and empirically validated new measures for *supply chain disruption impact* and *disruption management culture* as well as for the response strategies of *buffering* and *bridging*. The development of these constructs represents a contribution in itself, since the investigation of supply chain disruptions has relied on case study research, and still lacks developed and validated measures that can be used in further survey research. The sound fit of the measurement model indicates that the proposed constructs are meaningful for the phenomenon under investigation and thus could be relevant in subsequent studies.

6 Managerial and research implications

As performance aspects were not in the scope of this study, direct normative statements about how firms *should* respond to supply chain disruptions cannot be inferred from the results. Both buffering and bridging strategies may be effective and efficient depending on the specific context. Given this background, this study has three important messages for managerial practice.

First, purchasing managers should be careful in their relationships in which there is a high dependence on a specific supplier. Although this point appears trivial and well-explored at first glance (e.g., Bourantas, 1989), the results provide novel insights into this issue, namely that a high dependence on a supplier places substantial constraints on the focal firm’s span of responses in the aftermath of a supply chain disruption. Closely related to this point, this research provides

managers with insights into when either buffering or bridging strategies are typical responses to supply chain disruptions.

Second, supply chain managers can improve their firm's supply chain disruptions response capabilities by cultivating a strong disruption management culture. Research on high reliability organizations describes the cultural traits of organizations that thrive in turbulent environments and suggests possible courses of action (e.g., Roberts et al., 1994). This study points out that preoccupation with preventing failure, continuous improvement processes, and open communication about errors are cultural features which help a firm to become more responsive to supply chain disruptions.

Third, the results make a strong case for organizational learning from supply chain disruptions. They showed how a supply chain disruption provides incentive to investigate and improve the status quo. However, firms should not wait for a serious supply chain disruption before they learn how to understand latent vulnerabilities. A process of inquiry seeking latent deficiencies should be actively initiated in a preventive manner. The capability of anticipating and reducing the impact of potential vulnerabilities may create a significant competitive advantage in terms of supply chain reliability.

With regard to research implications, several directions for future research can be highlighted. First, it is generally difficult to determine the root cause of an observed change, and whether it is a response based on learning, such as understanding the relationship of that response to the experienced vulnerability (Fiol and Lyles, 1985). Although this study is based on a solid theoretical background, it cannot provide direct evidence that the organizational response is based on organizational learning.

Second, one has to be cautious regarding the rationality of the decision maker in the acute and resolution stages of a disruption. Individuals and groups of individuals do not always behave in a rational manner under conditions of

uncertainty, stress, and inexperience (Janis and Mann, 1977; Kahneman and Tversky, 1979). Therefore, in the face of a supply chain disruption, extreme stress may distort the perception and interpretation of the situation (Starbuck, Greve, and Hedberg, 1978). The intense pressure for action during the acute stage of a supply chain disruption may trigger ill-considered initiatives and prevent a rational analysis of the situation (Staw, Sandelands, and Dutton, 1981).

As supply chain disruptions are rare, there is a constant threat that they do not receive sufficient attention. The reason for this is that managers generally do not get credit for preventing disruptions that never occur, especially if the potential consequences are not known in advance. Therefore, an interesting question is whether companies, over the course of time, forget what they have learned from a serious supply chain disruption (Starbuck et al., 1978). Another aspect of interest is the effect of conflict and emotions on the response to supply chain disruptions. Conceptual framework III was based on resource dependence theory which assumes that organizations are rational. In contrast, social exchange theory (Blau, 1964; Homans, 1961; Thibaut and Kelley, 1959) refers to emotions and sentiments (e.g., blame, dissatisfaction), and thus might be relevant for analyzing emotional reactions to supply chain disruptions, such as the focal firm blaming the supplier for causing the disruption. Finally, collecting data from both sides of the relationship dyad would represent an interesting and promising task for future research. Various factors such as the comparative level of each firm's dependence can only be examined by using such dyadic data.

Chapter 5 Summary, limitations, and outlook

This chapter summarizes the previous chapters and presents the theoretical and managerial implications of the results and the models, as tested in Chapter 2, Chapter 3, and Chapter 4. It begins with a recapitulation of the main results with regard to the three research questions posed in the introductory chapter. This is followed by a delineation of the major academic contributions and the most relevant managerial implications. Finally, alternative theoretical views on the supply chain disruption phenomenon are identified and directions for future research are pinpointed.

1 Summary and review of the research questions

As described in Chapter 1, a growing number of scholars and practitioners have put the topic of supply chain risk and supply chain disruptions on their agendas. During the last years, the interest in this issue has gained momentum, driven by a combination of two factors: (1) increasingly turbulent business environments due to tougher competition as well as globalization of supply chains and markets, amongst others, and (2) prevalence of ever-more complex, tightly coupled, and fragile supply chain designs. Numerous anecdotes and case studies convey how disrupted supply chains can have severe negative consequences for the firms involved in such incidents, even to the point of jeopardizing their survival. The bulk of supply chain risk research has relied heavily on these examples and on case study methodologies, yet often with rhetorical or vague suggestions that lack theoretical foundation and quantitative substantiation. Given these circumstances, the objectives of this dissertation were to study supply chain disruptions in more detail and to advance the current understanding of such phenomena.

First, the pertinent literature was thoroughly reviewed in Chapter 1. Particular emphasis was put on the clarification of the terminology relevant in the domain of supply chain disruptions. This encompassed the concepts of *supply chain risk*, *supply chain disruption*, *supply chain risk source*, *supply chain vulnerability*, and *supply chain risk management*, all of which were defined and discussed in the context of the literature. In addition, a fine-grained classification of supply chain risks was proposed in the form of five supply chain risk sources, i.e., (1) *demand side risk*, (2) *supply side risk*, (3) *regulatory, legal, and bureaucratic risk*, (4) *infrastructure risk*, and (5) *catastrophic risk*. The nomenclature and the outlined supply chain risk source classification served as starting point for the subsequent chapters.

The research presented in Chapters 2, 3, and 4 followed a theory-driven, empirical approach and is based on two large-scale data gathering efforts: Study 1 and Study 2. In both cases, data were gathered by means of an internet-based survey of executives in the German-speaking countries of Austria (only Study 2), Germany (Study 1 and Study 2), and Switzerland (only Study 2). In Chapter 1, Study 1 and Study 2 were described in detail including the applied data collection procedures and the characteristics of the drawn samples. The obtained data sets (Study 1: $n = 760$; Study 2: $n = 455$) constituted a rich empirical basis for the investigation of the research questions outlined in Section 3 of Chapter 1.

At the heart of this dissertation, three research questions were investigated in Chapters 2, 3, and 4. Relying on three model-based approaches and by applying several theoretical concepts (i.e., normal accident theory, contingency perspective/strategic choice theory, resource dependence theory, and organizational learning theory), this dissertation makes an original contribution to the research field. In the following, the results with respect to these three research questions are summarized.

1.1 Research Question I

Research Question I tapped into the relationship between supply chain characteristics and supply chain risk, i.e., the exposure of a supply chain to supply chain disruptions. This is closely connected to the issue of supply chain vulnerability. The research question was:

Question I: *Are there supply chain characteristics that are positively related with supply chain risk and, thus, can be conceived as drivers of supply chain vulnerability?*

To answer this question and to understand the relationship between supply chain characteristics, supply chain vulnerability, and supply chain risk, the research presented in Chapter 2 drew from organizational theory that explains how accidents in socio-technical systems unfold and which system characteristics increase the likelihood of their occurrence and severity. For this purpose, normal accident theory was considered which contends that accidents in socio-technical systems are likely to occur under conditions of (1) high interactive complexity and/or (2) very tight coupling. Based on this theory, the central idea behind the conceptual framework was that supply chains are more vulnerable to disruptions if they exhibit a high degree of interactive complexity and/or a high degree of tight coupling. Hence, supply chain vulnerability was explained by normal accident theory in the sense that supply chain characteristics that contribute to either interactive complexity or tight coupling, drive the vulnerability of the supply chain.

Following a comprehensive literature review, several supply chain characteristics that had been proposed as relevant for a firm's supply chain vulnerability were identified. This resulted in five supply chain vulnerability drivers: (1) *supplier dependence*, (2) *customer dependence*, (3) *supplier concentration*, (4) *single sourcing*, and (5) *global sourcing*. Subsequently, hypotheses were formulated that relate these observable supply chain design attributes to supply chain risk. Supply chain risk was measured by asking the

respondents to indicate the cumulative negative consequences their firms had suffered due to supply chain disruptions during the last three years.

With regard to Research Question I, the findings from the five linear models estimated independently by OLS regression provide support for the assumption that four of the five examined supply chain characteristics (customer dependence, supplier dependence, single sourcing, and global sourcing) affect the amount of loss and damage a firm sustains as a result of supply chain disruptions. Hence, these factors can be conceived as drivers of supply chain vulnerability. In contrast, supplier concentration showed no enhancing impact on supply chain risk. In general, this is an important contribution as this is the first empirical approach to study supply chain vulnerability drivers and their relationship with supply chain risk. The results reveal that supply chain design directly affects the loss and damage a firm incurs from supply chain disruptions. Nonetheless, the examined supply chain vulnerability drivers only marginally explained the variance in supply chain risk. This calls for a further investigation of supply chain characteristics in the light of supply chain vulnerability.

1.2 Research Question II

According to the contingency perspective and strategic choice theory, the better a firm's structure is aligned with its task environment, and especially its environmental opportunities and threats, the better its performance. Recent literature has proclaimed that risks in the context of supply chains represented an environmental threat to organizations and, moreover, that many organizations were not sufficiently adapted. Cross-linking the notion of strategic fit with this supply chain risk issue, there had been a call for the adaptation of more robust and resilient supply chain designs. However, supply chain risk management is costly, while at the same time, its benefits are hard to estimate. This is because the relationship between supply chain risk and supply chain performance has not yet been well explored. Sound supply chain decision making, which seeks to determine an

optimal allocation of resources, requires a better understanding of the risk-performance relationship. In Chapter 3, Research Question II explores this relationship:

Question II: *Do supply chain risks have a significant impact on supply chain performance, and if yes, which supply chain risk sources are of relevance?*

As discussed in Chapter 3, so far, the event study-based works of Hendricks and Singhal (2003; 2005a; 2005b) are unique in empirically investigating this question. However, their work has several limitations, the most serious being that their sample contained only firms that *as a matter of fact* experienced a severe supply chain disruption. The research presented in Chapter 3 complements their work by addressing these limitations.

The results from the linear model estimated by OLS regression pointed to two relevant factors: demand side risk and supply side risk. In the estimated model, these were the only two supply chain risk sources that showed a negative influence on supply chain performance; regulatory, legal, and bureaucratic risk, infrastructure risk, as well as catastrophic risk had no significant impact. Hence, the findings support the assumption that supply side risk and demand side risk are relevant contextual variables for strategic supply chain decision making. At the same time, however, as in terms of regulatory, legal, and bureaucratic risk, infrastructure risk, and catastrophic risk, the study yielded no empirical support for a negative relationship with supply chain performance, the results attenuate the hyped discussion on supply chain risk. In addition, the results reveal a significant, but rather low impact of supply chain risks experienced by firms operating in Germany on supply chain performance. In the context under investigation, supply chain risk do not have a large effect on supply chain performance.

1.3 Research Question III

In order to understand supply chain disruptions, one must delve into how firms respond to supply chain disruptions and, especially, into the determinants and processes that influence the organization's decision making. It is also important to understand whether or not supply chain disruptions create an opportunity for organizational learning. As this issue had not received any consideration in the literature, Research Question III addressed this research gap and was formulated as:

Question III: *How does an organization respond to an experienced disruption?*

In Chapter 4, an attempt was made to unravel how supply chain disruptions generate organizational responses. Drawing from resource dependence theory and from the literature on organizational learning and organizational culture, this research suggested that a disruption in the supply chain stimulates organizational learning and adaptation as firms attempt to ameliorate the impact of future potential disruptions. Moreover, a firm's response to a supply chain disruption is intended to reduce the vulnerability experienced and follows the generic patterns of buffering and/or bridging. Building upon this central hypothesis, a model was developed that links the severity of a supply chain disruption with the organizational response strategies of buffering and bridging. In this context, the relevance of inter-organizational trust and dependence, as well as of organizational culture were investigated.

Covariance-based structural equation modeling technique was used to analyze the model with the data set from Study 2. The results offer several original insights and make several scholarly and managerial contributions. In detail, the results suggest that the concept of organizational learning provides explanatory power for the understanding of a firm's response to supply chain disruptions. The results indicate that the severity of a supply chain disruption has a positive impact on buffering and on bridging. Moreover, both trust in and dependence on the

involved supplier are important in the way a focal firm exercises its choice with regard to the two response strategies. Finally, organizational culture, which was conceptualized on the basis of research on high reliability organizations, seems to be a crucial factor for the post-disruption behavior of a firm.

2 Major academic contributions

The research presented in this dissertation contributes to the academic discussion in multiple ways. As the specific findings and research implications have already been extensively discussed in Chapters 2, 3, and 4, this section focuses on the more general aspects.

Overall, by using survey data with a large number of respondents, and by developing and testing theory-driven conceptual models, this dissertation moves beyond the case study-based and normative research that dominates the literature on supply chain risk.

Supply chain risk nomenclature

So far, the literature has lacked a universally accepted and rigorous terminology, but is replete with a myriad of definitions and conceptualization. Arguably, this has muddled the view on the phenomenon of supply chain disruptions and hindered research in this field. For this reason, the first contribution of this dissertation is the outlined nomenclature framework (depicted in Figure 1) which provides concise and consistent definitions that integrate many of the existing terms and concepts, and combines insights from the literature on supply chain management, operations management, marketing, and organizational crisis. Overall, the framework constitutes a thorough groundwork for future research in this area.

Fine-grained view on supply chain risks

The task of ordering, classifying, and grouping of the objects or phenomena under investigation has been described as an important prerequisite for advanced research steps (e.g., Bailey, 1994; Carper and Snizek, 1980). Although numerous classifications and typologies of supply chain disruptions have been proposed, empirical studies have so far neglected to take a sufficiently fine-grained view on supply chain risk and disruptions.

This dissertation moves beyond these conceptual classifications by proposing and testing an empirically-derived taxonomy. For this purpose, a set of the most relevant supply chain disruptions was singled out from the literature, discussed with practitioners and experts, and then tested using the large-scale survey data set obtained from Study 1. The five supply chain risk sources and their measures are the first empirical attempt to capture supply chain risk on a fine-grained basis. The classification and its empirical validation (in terms of exploratory and confirmatory factor analyses) in Chapter 2 and Chapter 3 provide important contributions to the academic discussion. The solid operationalization of supply chain risk sources may serve as a starting point for further studies.

Development and validation of new constructs and measures

Numerous novel constructs were defined, and appropriate measures developed and validated (an overview of these measures appears in Appendix 1). The development of precise constructs is essential for their use in empirical studies and, consequently, for theory testing. In the performed factor analytical tests, all developed measurement scales showed satisfactory psychometric properties. Consequently, these constructs are an important initial step towards further empirical research in this field. Apart from the measures for the five supply chain risk sources, especially the measures for the organizational response strategies of *buffering* and *bridging*, and the measure for *disruption management culture* are novel to the field of supply chain management.

Application of innovative theoretical perspectives

Several innovative theoretical views on the topic of supply chain disruptions were introduced. The three delineated conceptual frameworks are unique in applying normal accident theory (Chapter 2), contingency perspective and strategic choice theory (Chapter 3), organizational crisis theory (Chapter 4), organizational learning theory (Chapter 4), and resource dependence theory (Chapter 4) to the context of supply chain disruptions. In contrast to the other chapters, Chapter 4 adopts a multiple-theoretic perspective by integrating resource dependence theory and organizational learning theory into a single model. The relation that was pinpointed between supply chain disruptions and organizational crises is promising and insightful, as shown by adapting Fink's (1986) four-stage organizational crisis process model to supply chain disruptions. As there is a rich body of literature on organizational crises, the interconnected view of organizational crises and supply chain disruptions is able to support further studies on supply chain disruptions.

To the best of the author's knowledge, none of the current literature has applied these theories to supply chain risk and disruptions. In this regard, this dissertation blazes a new trail. The theoretical underpinnings were shown to be insightful for the understanding of supply chain disruptions and hint at numerous directions for future research (as described in Section 5).

3 Major implications for practice

The insights from the conceptual frameworks have significant implications for practitioners. As most of these implications have already been discussed in depth, only the most important general points are summarized here.

Supply chain risk sources

The effective management of supply chain disruptions is an important business challenge, as shown by the results of Chapters 2 and 3. The precise classification of

supply chain risk sources is a prerequisite for the identification and analysis of supply chain disruptions, as well as for the implementation of adequate supply chain risk management. Practitioners can utilize the supply chain risk sources framework to evaluate their supply chain designs and supply chain risk exposure, allowing them to develop an appropriate basis for decision making.

Drivers of supply chain vulnerability

In providing a more rigorous assessment of supply chain vulnerability drivers and their impact on supply chain risk, the findings of Chapter 2 offer hints to managers about the aspects of supply chain design that lead to more disruption-prone supply chains. The insights from normal accident theory can assist practitioners in assessing the impact of supply chain management strategies, like outsourcing or supply base reduction, in the light of interactive complexity and tight coupling. The message for managers is: reduce the complexity and loosen the coupling in your supply chains! Although both factors may appear rather abstract in research terminology, Chapter 2 explained how they may be driven by observable supply chain characteristics. Supply chain decision makers are well advised to be attentive to these two aspects in their supply chain designs. This also has ramifications for supply chain management education. While most of the popular supply chain management textbooks devote a significant space to supply chain design issues, they provide poor analyses of alternative supply chain structures in the light of their relative advantages with regard to supply chain vulnerability.

Prioritization of supply chain disruptions and strategic fit

Hendricks and Singhal (2003; 2005a; 2005b) found empirical support that supply chain disruptions have a significant adverse effect on both shareholder value and on operational performance. However, their research did not distinguish different sources of supply chain disruptions. This dissertation compensates for this oversight. As discussed in Chapter 3, supply side risk and demand side risk seem to

have a significant negative impact on supply chain performance, while other supply chain risk sources did not show such effects. This finding helps supply chain managers to prioritize their supply chain risk management efforts. At least, they should pay attention to these two supply chain risk sources, particularly when there is a strong dearth of resources for supply chain risk management.

In addition, these results can be taken as indications that supply side risk and demand side risk are relevant contextual variables for strategic supply chain decision making. Borrowing from strategic choice theory and strategic management literature, this leads to the need to reevaluate the strategic fit between supply chain design and the environment. As delineated, a certain supply chain design may perform well under usual conditions, but not necessarily during and after a supply chain disruption. Therefore, Chapter 3 suggested that current supply chain designs should be (re-)assessed in the light of supply side risk and demand side risk.

Learning from supply chain disruptions

Supply chain disruptions happen every day and many supply chain decision makers view these events merely as “unfortunate facts of life,” but not so much as potential sources of learning. Based on the organizational learning literature, the findings of Chapter 4 should encourage managers to conceive supply chain disruptions as opportunities for improvement and to leverage this potential as soon as the occurrence of a supply chain disruption has been detected. First, a supply chain disruption subjects the current supply chain design as well as the relationships with suppliers and customer to a major stress test, revealing latent flaws and dysfunctional system behaviors. Valuable inferences regarding stability and performance may be drawn from the system behavior during the stages of the supply chain disruption.

Second, the organizational response to a supply chain disruption, even if it has the appearance of a never recurring one-shot decision, should be carefully assessed in terms of efficiency and effectiveness. A structured post-event debriefing

phase may be an important factor for successful learning. The observations and experiences during the stages of a supply chain disruption can be exploited for learning and refining the response behavior.

Disruption management culture

Chapter 4 examined the relationship between organizational culture and the responsiveness to supply chain disruptions. It reveals organizational culture as a powerful asset for successfully coping with supply chain disruptions. For this reason, managers should cultivate a disruption management culture. In dealing with supply chain disruptions and to create an appropriate disruption management culture, the conceptualization presented in Chapter 4 (i.e., preoccupation with supply chain disruptions, sensitivity to operations, commitment to resilience, and a continuous improvement process) gives directions for action.

However, organizational culture is a phenomenon that is hard to grasp, and changing organizational cultures is typically a long-term endeavor (Schein, 2004). Therefore, for larger firms, a promising approach might be the creation of the position of a *chief supply chain risk manager* who not only steers the supply chain risk management activities and monitors the firm's supply chain vulnerability, but who also engages in forming a proper disruption management culture. Ideally, this role would be given the internal power and influence that it needs to drive the mind shift towards the creation of a desirable a supply chain disruptions management culture.

4 Limitations

4.1 Data gathering and statistical analyses

As with any empirical research, the results of this dissertation have to be assessed in light of the limitations under which the data were gathered and analyzed.

First, this dissertation concentrated on an area in supply chain management research where empirical research is limited. Solid statistical results obtained from the estimated confirmatory factor analysis models provide good indications for the factorial structure. However, the validation of scales is an inexact and iterative process. Thus, the constructs developed and validated in this dissertation need to be reexamined and their measures tested further to establish stronger confidence in their reliability and validity. Construct validity can only be accomplished through a series of studies that further refine and test the measures across populations and settings. A more profound investigation of the nomological network of the factors developed in this dissertation might yield a more parsimonious set of factors. Moreover, a few constructs were measured with a small number of items. Although, in these cases, the items showed high inter-correlations with other items in their scale, additional items would make the new scales more powerful.

Second, the models should be validated on other samples, if the findings are to be generalized unconditionally to the population of all firms. For example, the model investigated in Chapter 4 was tested with data gathered only from manufacturing companies (Study 2). This raises the question whether the model would also be validated with samples from other industries. Likewise, Study 2 focused solely on *supply side* supply chain disruptions and targeted purchasing managers as key informants. Replication with other supply chain risk sources (e.g., demand side) would be a consequential step.

Third, the surveys for Study 1 and Study 2, like many others in supply chain management research, targeted single well-informed respondents. While this was an important design step in keeping the surveys manageable, it also brings about the threat of a potential single informant bias which cannot completely be ruled out. A possible remedy for this problem may be the use of multiple informants (Wagner, Rau, and Lindemann, 2008).

A fourth limitation arises from the fact that in all estimated models, both explanatory and outcome variables are based on self-reports. This raises the

problem of common method variance in which the independent and dependent variables are hardly distinguishable (Bollen and Paxton, 1998; Phillips, 1981; Podsakoff and Organ, 1986). Despite the encouraging tests reported herein, the problem of common method variance cannot be completely ruled out. A bias arising from common method variance may be a greater problem for the results in Chapter 2 and Chapter 3, where the outcome variable *supply chain performance* may be vulnerable to a subjective perceptual measurement. In contrast, the results of Chapter 4 should be rather stable against this issue, since it is the perceived and subjective severity of the supply chain disruption that is decisive for the crafting of the response decision, and not necessarily the objective impact (Mintzberg et al., 1976).

Fifth, the data of Study 1 and Study 2 were collected from firms based in German-speaking countries (Austria, Germany, and Switzerland) which have quite similar cultures (Hofstede, 1980; Hofstede, 2003) and similar political, economic, and environmental conditions. As previous empirical studies in supply chain management have not reported any differences among these countries (e.g., Wagner, 2006b), the subsamples were treated as a single data set in the statistical analyses. However, the results may only be generalizable to firms based in countries with similar cultural, political, economic, and environmental setting. For example, regulatory, legal, and bureaucratic risk might be alleviated due to the fairly stable political and economic situation in the investigated countries. Moreover, as shown by Helferich and Cook (2002), the three countries are relatively immune to natural disasters. Hence, a replication of Study 1 and Study 2 in other countries with presumably different risk profiles (e.g., China or the US) would be a worthwhile next step (Study 2 has already been replicated in the USA).

Sixth, the response rates of the surveys (Study 1: 15.4%, Study 2: 11.8%) are a potential weakness. Other recent studies in the field of supply chain management have also struggled with response rates (e.g., Gibson et al., 2005; Sinkovics and Roath, 2004). Despite the encouraging results of tests of response bias reported

herein, the possibility that the respondents are professionals who are more concerned about and dedicated to supply chain disruption management, cannot be dismissed.

Finally, although the performed tests did not provide an indication of recall issues, recency bias might still exist in the data gathered in Study 2 due to the cross-sectional survey design. This problem can only be overcome by the use of longitudinal data which would enhance the understanding of the dynamic nature of the variables investigated.

4.2 Conceptual frameworks

Apart from these limitations associated with the empirical approach, the three conceptual frameworks and their testing exhibit limitations.

In Chapters 2 and 3, the rather low coefficients of determination (R^2) in all the estimated models indicate that partial models were investigated. Obviously, various other factors hold predictive power for the investigated dependent variables that were omitted in the conceptual frameworks. This has to be taken into consideration when interpreting the results.

In addition, in Chapters 2 and 3, the output-oriented (or downstream-oriented) supply chain performance measure from Rodrigues, Stank, and Lynch (2004) was used. For this reason, this scale cannot perform a more detailed examination of how supply chain disruptions affect other elements of supply chain performance such as performance in terms of resources and flexibility (Beamon, 1999).

Chapter 2 discussed only a selection of major disruptions and a variety of supply chain vulnerability drivers. The low coefficients of determination make a strong case for the further exploration of supply chain vulnerability and its drivers. A more precise operationalization of supply chain characteristics or design variables which are relevant for supply chain vulnerability together with an investigation of

their relationship with supply chain risk would be of high managerial relevance. A deeper knowledge of how supply chain characteristics increase or decrease vulnerability and consequently affect supply chain risk exposure would give managers important information for their decisions about supply chain design.

With regard to the conceptual framework presented in Chapter 4, several arguably relevant inter-organizational factors for the disruption response decision, such as transaction-specific investments (Williamson, 1985) and environmental contingency factors (e.g., Achrol and Stern, 1988), were not covered in the model.

5 Directions for future research

Apart from tying in with the limitation cited above, several additional avenues for future research seem promising. The following points should stimulate research interest and encourage further research in the area of supply chain risks and disruptions.

5.1 Model extensions and alternative theoretical underpinnings

The issues investigated in this dissertation can be viewed through the lenses of alternative theoretical approaches which could bring a new dimension to the research into supply chain disruptions.

5.1.1 Supply chain complexity

In Chapter 2, normal accident theory was applied to the supply chain context, in order to generate hypotheses concerning supply chain vulnerability. In particular, the concept of supply chain complexity was described. However, a closer investigation of supply chain complexity and its relationships with supply chain vulnerability and supply chain risk would be a promising next step. So far, there is no consensus on the precise definition of supply chain complexity. Vachon and Klassen (2002) outlined two dimensions that contribute to supply chain complexity:

(1) information processing and (2) technology. Choi and Hong (2002) borrowed the concept of structural complexity from the organizational science literature (e.g., Daft, 2006) and differentiated (1) horizontal, (2) vertical, and (3) spatial supply chain complexity. Finally, with regard to the supply base, Choi and Krause (2006) conjectured that (supply base) complexity is driven by (1) the number of suppliers, (2) the differentiation among the suppliers, and (3) the inter-relationships among the suppliers in the supply base. Based on these conceptual works, the development of an empirical testable construct “supply chain complexity” would allow a more precise rendering of normal accident theory in the supply chain risk context.

5.1.2 Configuration approaches

Chapter 3 used the contingency theory and strategic choice theory to argue that supply chain risk management could be of strategic importance for firms given the increasingly risky supply chain environment, particularly with regard to supply side and demand side risk. The contingency view contends that there is an association between environmental factors and organizational structure. If the environment changes, so does the organizational structure (deterministic view of contingency perspective); or it should be changed by decision makers (view of strategic choice theory). In any case, a strategic fit between environmental factors and organizational structure leads to superior performance.

Configuration theory is based on the former theories, but addresses successful organizational patterns. The premise is that a particular structure (configuration) will lead to better performance under some environmental conditions than under others. Hence, the more closely a supply chain matches an ideal constellation, the better the performance. Given certain environmental factors, groups of firms and supply chains emerge that display a common profile, i.e., configuration, of conceptually independent characteristics. For example, the typology by Miles and Snow (1978) which distinguishes four strategy-structure patterns (*prospectors*, *analyzers*, *defenders*, and *reactors*) was transferred to the

supply chain context (Hult, Ketchen, Cavusgil, and Calantone, 2006). Other supply chain classifications differentiate among *efficient* and *responsive* supply chains (Fisher, 1997), among *lean*, *agile*, *leagile*, and *hybrid* supply chains (Christopher and Towill, 2001; Goldsby, Griffis, and Roath, 2006), or among *built-to-stock*, *configure-to-order*, *build-to-order*, and *engineer-to-order* supply chains (Reeve and Srinivasan, 2005).

However, these environment-structure-performance contingencies have not been investigated against the background of supply chain risk. Adding the risk dimension to supply chain configurations (i.e., supply chain types), would lead to an intriguing investigation of how different supply chain types cope with supply chain disruptions.

5.1.3 Organizational learning theory

By applying the experienced-based learning perspective in conceptual framework III in Chapter 4, this dissertation provides a novel way of thinking about supply chain disruptions. However, various caveats to organizational learning from rare negative events have also been discussed in the literature (e.g., Levinthal and March, 1993; March et al., 1991).

First, since supply chain disruptions are infrequent, firms may also draw the “wrong” lessons from their experience and respond in an inadequate manner. Hence, there is no guarantee that firms learn the “right” lesson (i.e., learn reliably and validly) from a supply chain disruption. Chapter 4 looked at the organizational response only, and not at the performance aspects of the response. Therefore, an important and highly relevant extension to the investigated model is to include ex post performance measures.

The second issue is captured in the *threat-rigidity thesis* (Staw et al., 1981) which holds that under certain conditions individuals tend to respond in a rigid and inflexible manner to adversity and threat. For example, too much upheaval has been reported to inhibit organizational learning (Newman, 2000). Hence, the supply

chain disruptions-induced stress might also lead to a reliance on well-learned or dominant modes of thought or action. This would cause the firm to lock into a standard mode of cognition and response, thereby building rigidity and inertia, instead of using the creative thinking which is needed for a successful response to the supply chain disruption. The origins of rigidity effects lie in poor inter-organizational communication and information flow, confusion among organizational members, desires to avoid blame (blame-shifting), and insufficient preparation, amongst others (e.g., Staw et al., 1981). The closer investigation of such factors would complement the results of Chapter 4.

Third, as stated in Chapter 4, *oblivion* is a potential threat to learning from supply chain disruptions. In one of the interviews conducted, an operations manager from a large UK-based pharmaceutical company revealed that in his company, inventory levels had often been raised after a stock-out incident of an important product. However, over time the stock-out situation had faded from organizational memory (e.g., due to retirement or job rotation of the managers involved) and then, ultimately, the costly stock level was lowered again, because none of the responsible managers could remember why the level had been raised. Again, a closer investigation of this “oblivion effect” would be highly relevant for managerial practice in order to develop and implement countermeasures.

5.1.4 High reliability theory and the concept of mindfulness

Charles Perrow (1984) made an important contribution in identifying interactive complexity and tight coupling as major risk-increasing system characteristics. His conclusion, however, that accidents are inevitable in such systems has been criticized as overly pessimistic. In particular, high reliability theory has questioned the main implication of Perrow’s normal accident theory, arguing that organizational and structural precautions can reduce the likelihood of normal accidents (e.g., Roberts, 1990). High reliability theory examined organizations that show great proficiency in dealing with unexpected events, e.g. nuclear submarines

(Bierly and Spender, 1995). For example, according to high reliability theory, organizational culture plays a crucial important role in achieving superior performance in turbulent environments. Similarly, Langer (1989) introduces the concept of mindfulness as a state of permanent alertness and lively awareness. A culture of mindfulness encompasses organizational practices related to communication about errors, to sharing error knowledge, to preventing error situations, and to quickly detecting and handling errors. Mindfulness on the level of organizational culture was later proposed as an extension to high reliability theory (Weick, Obstfeld, and Sutcliffe, 1999).

Supply chain risk management may benefit from high reliability theory and the concept of mindfulness. From a research perspective, the examination of high reliability theory aspects alongside the concepts of interactive complexity and tight coupling (normal accident theory) is certainly interesting. For example, it could be that firms, which possess characteristics of high reliable organizations, can be successful even in the presence of interactive complexity and/or tight coupling in their supply chains. However, an issue might be that the high reliability theory literature is not always precise and sometimes even inconsistent. For example, it was suggested that organizations can buffer the impact of critical situations and make fewer mistakes through redundancy (Roberts, 1990). In contrast, it was also argued that redundancy may backfire in crisis situations (Sagan, 2004). Another suggestion was that the impact of critical situations could be reduced simply by giving personnel the right training. However, other studies contended that training can reduce flexibility, which could impair the organization's ability to respond during critical situations (Price, 1977; Price and Mueller, 1981). Therefore, the characteristics of highly reliable organizations have to be thoroughly examined in the context of supply chain management before further research steps can be taken.

5.1.5 Resource-based view

What capabilities would firms support in successfully managing their supply chain vulnerability and potential supply chain disruptions? This is an important question that practitioners are asking as firms around the world struggle with the growing risk of supply chain disruptions. Highlighting the importance of a disruption management culture, this dissertation provides some important, albeit partial answers to this question. Here, the resource-based view (RBV) (e.g., Barney, 1991; Penrose, 1959; Wernerfelt, 1984) may be helpful to support further research in this direction.

The RBV and its extensions argue that firms have exclusive access to resources (e.g., stocks of knowledge, physical assets, human capital, or other tangible or intangible factors) and that a subset of these resources enable them to achieve competitive advantage leading to superior long-term performance. This subset consists of resources that are valuable, inimitable, and that interact with each other in organizational structures, processes, and management systems. Firms use the capabilities developed by the utilization of their resources to manage their environment and to perform (Day, 1994). Against this background, a resource-based perspective on supply chain risk management seems a promising way to explore the organizational capabilities that would help firms to achieve competitive advantage. For example, insofar as a disruption management culture enables a firm to enhance the value of its stock of capabilities, it should lead to competitive advantage. Likewise, other capabilities should be investigated that help a firm to deal with supply chain disruptions and to create competitive advantage.

5.1.6 Models of accident causation

With the examination of supply chain vulnerability drivers as factors affecting the likelihood and severity of supply chain disruptions, this dissertation made an initial investigation of the causes of supply chain disruptions. The question of how accidents or crises unfold has been answered by a multitude of research streams,

and especially by researchers in the fields of engineering, systems safety, and psychology. Apart from normal accident theory and high reliability theory, several other models exist, such as Heinrich's domino model (Heinrich, Petersen, and Roos, 1980), the STAMP model developed at the Massachusetts Institute of Technology (Leveson, 2004), or Reason's Swiss cheese model (also pathogen model) (Reason, 1990).

Reason's model, for instance, distinguishes latent from active safety failures. Latent failures are the result of management decisions and can be grouped into a limited number of classes (general failure types), e.g., wrong system design, error-enforcing conditions, lack of communication, unsuitable work procedures, or incompatible goals. These imperfections remain dormant in the system and create "holes" in its safety layers (defense mechanisms). An accident is triggered by an active failure (corresponds to the triggering event of a supply chain disruption) that is not impeded by one of the system defenses because of the "holes" created by the latent failures. Figure 4 shows how Reason's model can explain a supply chain disruption. As this model has proven its exploratory power for the investigation and analysis of industrial accidents, it might also support further investigations into the causes and the emergence of supply chain disruptions.

5.2 Cross-country effects

Given the phenomenon of globalization and the increasing importance of international business, the transferability of models, theories, and practices across national borders and cultures has become an important issue in the social sciences. Comparing two or more data sets stemming from different cultural backgrounds is an essential means of discovering the peculiarity or universality of methods, attributes, theories or practices (De Beuckelaer and Wagner, 2007).

Against this background, it is important to note that the results, obtained on the basis of data from German-speaking countries, may not generalize to other

countries and cultures. An interesting next step is the replication of the studies in other countries with presumably different cultural orientations and practices, as has already been done in the USA with Study 3 (replication of Study 2). Regarding Study 2 and Study 3, where would one expect to find interesting country-specific variance? Prior research has argued that buyer-supplier relationships may differ between Germany and the US (e.g., Kaufmann and Carter, 2006). Furthermore, differences in the risk perception of supply managers have recently been reported between the two countries (Zsidisin, Wagner, Melnyk, Ragatz, and Burns, 2008). Therefore, for the investigation of supply chain disruptions, three of Hofstede's (2003) five dimensions of cultural difference (power distance, uncertainty avoidance, individualism/collectivism, masculinity/femininity, long-term/short-term orientation) can be expected to be of particular importance in the context of supply chain disruptions: uncertainty avoidance, individualism/collectivism, long-term/short-term orientation. For instance, supply chain managers in the USA could be expected to react differently to supply chain disruptions because of their focus on short-term results, in contrast to the more long-term oriented German counterparts.

5.3 Longitudinal research design

Neither Study 1 nor Study 2 was longitudinal; this precludes establishing a strong claim of causality in the estimated models. Many of the investigated aspects and theories are highly dynamic, such as the contingency perspective on supply chain risk or the organizational learning view on supply chain disruptions. Such qualities cannot be fully examined in a cross-sectional study, but should be addressed with a longitudinal approach. Certainly, a longitudinal study of supply chain disruptions would enhance the knowledge of the ways in which firms adjust to supply chain risk and evaluate their responses to supply chain disruptions. In a similar vein, it would be useful to conduct longitudinal in-depth case studies with a small number of firms that have suffered from a supply chain disruption, in the hope of arriving at

a better understanding of the processes that lead to organizational responses to supply chain disruptions.

6 Conclusion and outlook

This dissertation constitutes a further step in the understanding of supply chain disruptions. As the previous sections have stated, it offers several unique insights into the causes (supply chain vulnerability) and effects (performance implications and organizational responses) of supply chain disruptions, and, at the same time, contributes to the academic discussion in the field and has relevant implications for practitioners.

In the epilogue to Bertold Brecht's famous play *The Good Person of Szechwan* (original title: *Der Gute Mensch von Sezuan*), the speaker turns directly to the audience and says: "Indeed it is a curious way of coping: / To close the play, leaving the issue open."⁸ Although this dissertation investigated several important questions and produced valuable results, many questions remain unanswered and there is ample room for further research. This dissertation has laid the groundwork for the investigation of several fascinating research questions. Finding answers to these questions will be an intriguing and rewarding task for many researchers.

⁸ Cited in Thomson and Sacks (2006, p. 126); originally in German: "Wir stehen selbst enttäuscht und sehn betroffen / Den Vorhang zu und alle Fragen offen" (Brecht, 1964, p. 144).

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Appendix

Appendix 1: Overview of constructs and their abbreviations

Construct	Construct abbreviation	Origin	Measurement items	Item cues
Demand side risk	DSR	New	DSR1 DSR2	See Table 5
Supply side risk	SSR	New	SSR1 SSR2, SSR3 SSR4, SSR5	See Table 5
Regulatory, legal, and bureaucratic risk	BUR	New	BUR1 BUR2	See Table 5
Infrastructure risk	IFR	New	IFR1 IFR2 IFR3 IFR4	See Table 5
Catastrophic risk	CTR	New	CTR1 CTR2 CTR3 CTR4	See Table 5
Customer dependence	VULA	New	VULA	See Table 5
Supplier dependence	VULB	New	VULB	See Table 5
Supplier concentration	VULC	New	VULC	See Table 5
Single sourcing	VULD	New	VULD	See Table 5
Global sourcing	VULE	New	VULE	See Table 5
Supply chain performance	PFC	Rodrigues, Stank, and Lynch (2004)	PFC1 PFC2 PFC3 PFC4	See Table 9
Supply chain risk management	SCR	New	SCR1 SCR2 SCR3 SCR4 SCR5 SCR6	See Table 9
Disruption impact	IMP	New	IMP2 IMP3 IMP5 IMP6 IMP7 IMP8	See Table 15

Construct	Construct abbreviation	Origin	Measurement items	Item cues
Dependence (on a supplier)	DEP	Jap and Ganesan (2000)	DEP1 DEP2 DEP3 DEP4	See Table 15
Trust (in a supplier)	TRU	Doney and Cannon (1997)	TRU1 TRU2 TRU3 TRU4 TRU6	See Table 15
Disruption management culture	CUL	New	CUL1 CUL2 CUL3 CUL4 CUL5	See Table 15
Buffering (response strategy)	BUF	New	BUF1 BUF2 BUF4	See Table 15
Bridging (response strategy)	BRI	New	BRI1 BRI2 BRI3 BRI4 BRI5	See Table 15

Appendix 2: List of items that were removed during the scale purification process (Chapter 4)

Construct name	Eliminated item	
(1) Disruption impact (IMP)	IMP1	Procurement costs/Prices for the purchased item.
	IMP4	Responsiveness to customer demands.
(2) Dependence (DEP)	–	No item eliminated.
(3) Trust (TRU)	TRU5	This supplier was genuinely concerned that our business succeeds.
	TRU7	We trusted this supplier to keep our best interests in mind.
	TRU8	We did not find it necessary to be cautious with this supplier.
	–	No item eliminated.
(4) Disruption management culture (CUL)	–	No item eliminated.
(5) Buffering (BUF)	BUF3	Build up additional inventory buffers of the purchased item.
	BUF5	Change our final product layout or production processes to become less dependent on this supplier or the purchased item.
(6) Bridging (BRI)	–	No item eliminated.

Note. All items were measured on five-point rating scales (Likert-type) (see Table 12).

Appendix 3: Inter-item correlation table (Chapter 2)

Item	DSR1	DSR2	SSR1	SSR2	SSR3	SSR4	SSR5	BUR1	BUR2	IFR1	IFR2	IFR3	IFR4	CTR1	CTR2	CTR3	CTR4	VULA	VULB	VULC	VULD	VULE	SCR1	SCR2	SCR3	SCR4	SCR5	SCR6					
<i>Demand side r.</i>																																	
DSR1	1																																
DSR2	0.57**	1																															
SSR1	0.24**	0.32**	1																														
SSR2	0.29**	0.34**	0.62**	1																													
SSR3	0.15**	0.22**	0.47**	0.50**	1																												
SSR4	0.19**	0.25**	0.54**	0.44**	0.37**	1																											
SSR5	0.35**	0.32**	0.44**	0.48**	0.35**	0.24**	1																										
BUR1	0.11**	0.11**	0.22**	0.19**	0.22**	0.22**	0.15**	1																									
BUR2	0.07	0.14**	0.28**	0.24**	0.27**	0.35**	0.24**	0.53**	1																								
IFR1	0.10**	0.13**	0.14**	0.21**	0.17**	0.24**	0.16**	0.15**	0.18**	1																							
IFR2	0.08*	0.15**	0.22**	0.18**	0.19**	0.29**	0.18**	0.29**	0.28**	0.43**	1																						
IFR3	0.17**	0.21**	0.23**	0.26**	0.20**	0.28**	0.22**	0.17**	0.31**	0.58**	0.34**	1																					
IFR4	0.09*	0.16**	0.20**	0.20**	0.22**	0.28**	0.18**	0.28**	0.28**	0.36**	0.58**	0.29**	1																				
CTR1	0.10**	0.07	0.18**	0.20**	0.24**	0.23**	0.20**	0.28**	0.24**	0.17**	0.17**	0.19**	0.24**	1																			
CTR2	0.08*	0.06	0.14**	0.12**	0.20**	0.19**	0.12**	0.29**	0.24**	0.16**	0.15**	0.22**	0.22**	0.72**	1																		
CTR3	0.10**	0.12**	0.15**	0.18**	0.24**	0.22**	0.14**	0.26**	0.18**	0.14**	0.14**	0.18**	0.19**	0.58**	0.49**	1																	
CTR4	0.12**	0.12**	0.21**	0.19**	0.26**	0.25**	0.20**	0.23**	0.17**	0.20**	0.19**	0.17**	0.22**	0.58**	0.51**	0.67**	1																
VULA	0.17**	0.19**	0.05	0.05	0.02	0.03	0.02	0.02	0.08*	0.08**	0.04	0.15**	0.09*	0.02	0.03	0.02	-0.01	1															
VULB	0.15**	0.17**	0.30**	0.23**	0.14**	0.01**	0.20**	-0.02	0.06	0.12**	0.09**	0.13**	0.02	-0.01	-0.05	-0.07	0.00	0.25**	1														
VULC	0.10**	0.09*	0.06	0.05	0.00	0.03	0.02	-0.02	0.04	0.11**	0.06	0.13**	0.03	0.03	0.02	0.01	0.02	0.10**	0.32**	1													
VULD	0.12**	0.10**	0.21**	0.15**	0.15**	0.15**	0.03	0.10**	0.11**	0.11**	0.14**	0.15**	0.08*	0.02	0.03	0.04	0.00	0.13**	0.40**	0.31**	1												
VULE	0.03	0.05	0.16**	0.16**	0.18**	0.10**	0.18**	0.04	0.07	-0.05	0.08*	0.00	0.06	0.13**	0.12**	0.15**	0.14**	-0.20**	0.07	-0.05	0.10**	1											
SCR1	0.01	-0.04	0.09*	0.06	0.01	0.08*	0.06	0.10**	0.01	0.06	0.02	0.10**	0.04	-0.01	0.04	0.05	0.09*	0.09*	0.07**	0.09*	0.09*	0.27**	1										
SCR2	-0.01	-0.08*	0.01	0.02	0.01	-0.01	0.04	0.09*	0.10**	-0.02	-0.01	0.04	0.06	0.08*	0.13**	0.05	0.08*	0.02	-0.03	0.07*	0.02	0.05	0.59**	0.59**	1								
SCR3	0.00	-0.04	0.12**	0.16**	0.09*	0.06	0.12**	0.08*	0.06	-0.02	0.04	-0.02	0.03	0.09*	0.08*	0.09*	0.05	-0.07	0.09*	0.11**	0.11**	0.35**	0.52**	0.46**	0.46**	1							
SCR4	0.03	-0.02	0.11**	0.09*	0.12**	0.13**	0.14**	0.09*	0.08*	0.00	0.05	0.08*	0.06	0.04	0.07	0.07	0.04	-0.09*	0.05	0.06	0.13**	0.24**	0.43**	0.36**	0.42**	0.42**	1						
SCR5	-0.03	-0.05	0.05	0.05	0.05	0.02	0.04	0.08*	0.07	-0.05	0.02	-0.03	0.04	0.09*	0.13**	0.05	0.12**	-0.01	0.00	0.02	0.04	0.27**	0.39**	0.45**	0.36**	0.23**	0.23**	1					
SCR6	0.01	-0.02	0.08*	0.09*	0.01	0.08*	0.07	0.05	0.06	0.03	0.09*	0.05	0.09*	0.05	0.05	0.02	0.04	0.02	0.02	0.02	0.05	0.23**	0.37**	0.36**	0.39**	0.28**	0.30**	0.30**	1				
M	3.43	3.08	2.68	2.80	2.03	2.16	2.68	2.31	2.08	1.56	1.80	1.83	1.71	1.59	1.61	1.47	1.51	3.35	3.03	2.80	2.41	3.00	3.14	2.73	3.01	2.71	2.18	2.61					
SD	1.10	1.14	1.09	1.03	1.03	0.93	1.08	1.12	1.03	0.84	0.87	0.93	0.88	0.89	0.92	0.87	0.84	1.27	1.23	1.11	1.14	1.37	1.20	1.33	1.15	1.20	1.28	1.21					

Note. Pearson correlation coefficients are shown.

* $p < 0.05$, ** $p < 0.01$ (two-tailed).

Supply chain risk management

Catastrophic risk

Infrastructure risk

BUR

Supply side risk

Appendix 4: Inter-item correlation table (Chapter 3)

Item	DSR1	DSR2	SSR1	SSR2	SSR3	SSR4	SSR5	BUR1	BUR2	IFR1	IFR2	IFR3	IFR4	CTR1	CTR2	CTR3	CTR4	PFC1	PFC2	PFC3	PFC4	SIZE
<i>Demand side risk</i>																						
DSR1	1																					
DSR2	0.57**	1																				
<i>Supply side risk</i>																						
SSR1	0.24**	0.32**	1																			
SSR2	0.29**	0.34**	0.62**	1																		
SSR3	0.15**	0.22**	0.47**	0.50**	1																	
SSR4	0.19**	0.25**	0.54**	0.44**	0.37**	1																
SSR5	0.35**	0.32**	0.44**	0.48**	0.35**	0.24**	1															
<i>BUR</i>																						
BUR1	0.11**	0.11**	0.22**	0.19**	0.22**	0.22**	0.15**	1														
BUR2	0.07	0.14**	0.28**	0.24**	0.27**	0.35**	0.24**	0.53**	1													
<i>Infrastructure risk</i>																						
IFR1	0.10**	0.13**	0.14**	0.21**	0.17**	0.24**	0.16**	0.15**	0.18**	1												
IFR2	0.08*	0.15**	0.22**	0.18**	0.19**	0.29**	0.18**	0.29**	0.28**	0.43**	1											
IFR3	0.17**	0.21**	0.23**	0.26**	0.20**	0.28**	0.22**	0.17**	0.31**	0.34**	0.34**	1										
IFR4	0.09*	0.16**	0.20**	0.20**	0.22**	0.28**	0.18**	0.28**	0.36**	0.58**	0.58**	0.29**	1									
<i>Catastrophic risk</i>																						
CTR1	0.10**	0.07	0.18**	0.20**	0.24**	0.23**	0.20**	0.28**	0.24**	0.17**	0.17**	0.19**	0.24**	1								
CTR2	0.08*	0.06	0.14**	0.12**	0.20**	0.19**	0.12**	0.29**	0.24**	0.16**	0.15**	0.22**	0.22**	0.72**	1							
CTR3	0.10**	0.12**	0.15**	0.18**	0.24**	0.22**	0.14**	0.26**	0.18**	0.14**	0.14**	0.18**	0.19**	0.58**	0.49**	1						
CTR4	0.12**	0.12**	0.21**	0.19**	0.26**	0.25**	0.20**	0.23**	0.17**	0.20**	0.19**	0.17**	0.22**	0.58**	0.51**	0.67**	1					
<i>Supply chain performance</i>																						
PFC1	-0.10*	-0.10**	-0.07	-0.04	-0.04	-0.07	-0.06	-0.01	-0.04	-0.04	-0.08*	-0.10**	-0.07	-0.03	-0.02	-0.04	-0.04	1				
PFC2	-0.05	-0.06	-0.07	-0.04	-0.04	-0.06	-0.07	-0.03	-0.02	-0.08*	-0.12**	-0.07	-0.06	-0.02	-0.07	-0.03	-0.03	0.72**	1			
PFC3	-0.10**	-0.15**	-0.11**	-0.10**	-0.06	-0.13**	-0.12**	0.00	-0.01	-0.04	-0.09*	-0.08*	-0.01	-0.01	0.00	-0.04	-0.03	0.57**	0.60**	1		
PFC4	-0.12**	-0.11**	-0.09**	-0.08*	-0.11**	-0.11**	-0.03	0.00	-0.02	-0.03	-0.05	-0.04	-0.01	-0.03	0.01	-0.06	-0.04	0.55**	0.63**	0.49**	1	
SIZE	-0.04	0.01	-0.07	0.02	0.04	0.02	-0.01	0.02	0.03	-0.03	0.01	-0.04	-0.02	0.01	0.02	0.02	0.02	0.01	0.02	-0.03	-0.04	1
M3.43	3.08	2.68	2.80	2.03	2.16	2.68	2.16	2.31	2.08	1.56	1.80	1.83	1.71	1.59	1.61	1.47	1.51	3.76	3.79	3.83	3.70	2.912
SD1.10	1.14	1.09	1.03	1.03	0.93	1.08	1.08	1.12	1.03	0.84	0.87	0.93	0.88	0.89	0.92	0.87	0.84	0.74	0.75	0.71	0.76	19.103

Note. Pearson correlation coefficients are shown.

* $p < 0.05$, ** $p < 0.01$ (two-tailed).

Appendix 5: Inter-item correlation table (Chapter 4)

Item	DEP1	DEP2	DEP3	DEP4	TRU1	TRU2	TRU3	TRU4	TRU6	IMP2	IMP3	IMP5	IMP6	IMP7	IMP8	BUF1	BUF2	BUF4	BR11	BR12	BR13	BR14	BR15	CUL1	CUL2	CUL3	CUL4	CUL5
DEP1	1																											
DEP2	0.75**	1																										
DEP3	0.65**	0.77**	1																									
DEP4	0.56**	0.69**	0.69**	1																								
TRU1	0.01	0.03	-0.03	-0.04	1																							
TRU2	0.03	0.00	0.00	-0.02	0.75**	1																						
TRU3	0.06	0.04	0.05	0.00	0.49**	0.60**	1																					
TRU4	0.07	0.03	-0.03	-0.05	0.56**	0.71**	0.69**	1																				
TRU6	0.17**	0.15**	0.10*	0.05	0.41**	0.52**	0.44**	0.54**	1																			
IMP2	0.26**	0.15**	0.12*	0.09	-0.18**	-0.10*	-0.02	-0.07	0.03	1																		
IMP3	0.04	0.00	0.02	-0.02	-0.18**	-0.16**	-0.06	-0.08	-0.09	0.28**	1																	
IMP5	0.23**	0.25**	0.19**	0.15**	-0.20**	-0.08	-0.06	-0.10*	0.01	0.35**	0.27**	1																
IMP6	0.14**	0.04	0.06	0.05	-0.14**	-0.10*	-0.06	-0.05	-0.06	0.33**	0.43**	0.21**	1															
IMP7	0.21**	0.19**	0.15**	0.09	-0.08	-0.03	0.00	-0.02	0.07	0.29**	0.25**	0.55**	0.28**	1														
IMP8	0.16**	0.08	0.03	0.02	-0.14**	-0.18**	-0.06	-0.09	-0.07	0.34**	0.34**	0.39**	0.30**	0.66**	1													
BUF1	-0.03	-0.05	-0.01	-0.04	-0.15**	-0.25**	-0.11*	-0.18**	-0.19**	0.04	0.17**	0.06	0.11*	0.08	0.15**	1												
BUF2	0.07	0.04	0.04	-0.04	-0.07	-0.08	-0.09	-0.03	-0.03	0.16**	0.11*	0.13**	0.10*	0.10*	0.15**	0.36**	1											
BUF4	-0.02	-0.02	-0.02	-0.03	-0.15**	-0.22**	-0.09*	-0.23**	-0.16**	0.09	0.11*	0.05	0.07	0.07	0.17**	0.65**	0.25**	1										
BR11	0.30**	0.26**	0.19**	0.14**	0.13**	0.20**	0.08	0.16**	0.21**	0.08	-0.01	0.15**	0.04	0.16**	0.13**	-0.06	0.18**	-0.01	1									
BR12	0.26**	0.24**	0.17**	0.18**	-0.03	0.00	-0.05	-0.02	0.03	0.14**	0.12*	0.19**	0.08	0.15**	0.12**	0.05	0.37**	0.07	0.52**	1								
BR13	0.30**	0.26**	0.20**	0.15**	0.12*	0.17**	0.04	0.15**	0.20**	0.13**	-0.03	0.16**	0.07	0.16**	0.11*	-0.07	0.19**	-0.03	0.73**	0.62**	1							
BR14	0.25**	0.22**	0.17**	0.13**	0.11*	0.19**	0.03	0.15**	0.17**	0.14**	-0.02	0.16**	0.04	0.16**	0.10*	-0.10*	0.20**	-0.05	0.68**	0.63**	0.78**	1						
BR15	0.23**	0.18**	0.19**	0.10*	0.12*	0.12*	0.02	0.12**	0.18**	0.14**	0.04	0.17**	0.08	0.18**	0.12*	-0.01	0.30**	0.02	0.54**	0.48**	0.56**	0.58**	1					
CUL1	0.21**	0.21**	0.18**	0.12**	-0.02	-0.03	0.00	-0.01	0.10*	0.07	-0.02	0.04	0.03	0.06	0.09	0.10*	0.30**	0.09*	0.16**	0.17**	0.15**	0.19**	0.23**	1				
CUL2	0.11*	0.08	0.07	0.08	0.01	-0.03	-0.03	0.02	-0.02	0.03	0.05	0.08	0.04	0.07	0.04	0.16**	0.25**	0.17**	0.19**	0.23**	0.17**	0.19**	0.22**	0.32**	1			
CUL3	0.14**	0.11*	0.09	0.05	0.06	0.07	0.07	0.05	0.04	0.03	-0.05	-0.03	-0.03	0.02	0.03	0.01	0.06	0.04	0.07	0.03	0.05	0.07	0.06	0.43**	0.25**	1		
CUL4	0.12**	0.11*	0.08	0.06	0.01	0.02	-0.05	-0.01	0.09*	0.07	-0.01	0.04	0.06	0.13**	0.15**	0.08	0.28**	0.15**	0.26**	0.27**	0.25**	0.28**	0.30**	0.45**	0.37**	0.34**	1	
CUL5	0.10*	0.09	0.09*	0.06	0.11*	0.09*	0.07	0.08	0.15**	0.03	0.10*	-0.03	0.06	0.07	0.06	0.15**	0.26**	0.15**	0.26**	0.27**	0.20**	0.24**	0.27**	0.35**	0.27**	0.30**	0.48**	1
M3.91	3.79	3.68	3.51	3.33	3.49	3.73	3.76	3.72	3.15	2.22	3.61	1.66	2.51	2.74	3.04	3.18	3.37	3.01	3.28	3.06	3.29	2.67	4.09	3.88	4.30	3.94	3.77	
SD	1.10	1.12	1.16	1.23	0.94	0.95	0.81	0.82	0.89	1.20	1.32	1.30	0.92	1.21	1.25	1.24	0.99	1.28	1.14	1.16	1.14	1.08	1.18	0.82	0.93	0.69	0.87	0.96

Note. Pearson correlation coefficients are shown.

* $p < 0.05$, ** $p < 0.01$ (two-tailed).