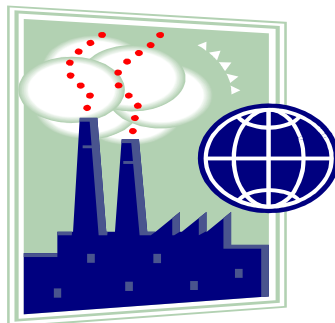


An empirical investigation into supply chain vulnerability



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1. Introduction

- In the past five years, a subject in the field of supply chain management research has gained considerable attention by both academicians and practitioners: supply chain risk management.
- The terrorist attacks on the World Trade Center on September 11, 2001, the SARS epidemic in South-East Asia in 2003, and the natural disaster of Hurricane Katrina in 2005 are three exemplary disasters and violent reminders that firms and their global supply chains operate in an unpredictable and increasingly uncertain environment.
- There is also a substantial body of recent literature that reports on events on the “supply chain level”, which resulted in serious problems for the involved firms (Norrman and Jansson, 2004; Sheffi, 2005).
- Christopher and Lee (2004) for instance argue that “the vulnerability of supply chains to disturbance or disruption has increased”.

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- This is due to a combination of several factors and trends. In recent years, almost all industries have witnessed fiercer competition and accelerated globalisation of markets. This resulted in a massive pressure to make intrafirm and interfirm business processes more efficient and/or more responsive.
- Results of large-scale empirical research on supply chain risk issues are scarce. In particular, current knowledge about the mechanisms and conditions that determine the vulnerability of supply chains and about the interaction of supply chain vulnerability and supply chain disruptions is quite limited.
- The purpose of this research is to investigate the relationship between a set of supply chain characteristics—which are supposed to provoke the vulnerability of supply chains—and the impact on the performance from three classes of supply chain disruptions.

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2. Literature review and hypotheses

2.1. Supply chain risk

- It is crucial for any study dealing with risk to define the term appropriately since it is an elusive construct with a variety of meanings, measurements, and interpretations depending on the field of research (Baird and Thomas, 1990; Jemison, 1987).
- Juttner et al. (2003) define supply chain risk as a “variation in the distribution of possible supply chain outcomes, their likelihood, and their subjective value”.
- Harland et al. (2003) for instance, discuss several definitions and conclude that supply chain risk is associated with the “chance of danger, damage, loss, injury or any other undesired consequences”.
- The purpose of this study and considering the impact of recent catastrophes on supply chains, we find that the latter notion of risk as purely negative is the one that corresponds best to supply chain business reality.

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2.2. Supply chain disruption and supply chain risk sources

- A supply chain disruption is an unintended, untoward situation, which leads to supply chain risk.
- It is triggered by an underlying disruptive event (or a series of such events). There has been intensive research by organisational scientists on events that adversely affect organisations, how organisational crisis emerge from those events, and how organisations react to them (Kovoor-Misra et al., 2001; Rijpma, 1997).
- The derived classes of supply chain disruptions are often labelled “supply chain risk sources”. We call a negative deviation from the expected value of a performance measure (resulting in negative consequences the focal firm) for example a “supply-side risk” .

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2.3. Supply chain vulnerability and its drivers

- Christopher and Peck (2004) define supply chain vulnerability as “an exposure to serious disturbance”.
- In the literature on natural hazard and crisis management, 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 et al., 1994).
- In the context of maritime supply chains, Barnes and Oloruntoba (2005) describe vulnerability as “a susceptibility or predisposition to (y) loss because of existing organisational or functional practices or conditions”.
- In this article, this latter definition is applied and the atomistic perspective (supply chain vulnerability on the individual firm level) is taken. We posit that supply chain vulnerability is a function of certain supply chain characteristics and that the loss a firm incurs is a result of its supply chain vulnerability to a given supply chain disruption.

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2.4. Hypotheses

- Demand-side risks can originate from the uncertainty surrounding the random demands of the customers (Nagurney et al., 2005). Disruptions occur here from a mismatch between a company’s projections and actual demand as well as from poor supply chain coordination. Consequence of which are costly shortages, obsolescence, and inefficient capacity utilisation. An important issue in this context, affecting forecast quality and therefore demand-side disruptions, is the bullwhip effect, which is characterised by an amplification of demand volatility in the upstream direction of the supply chain.

H1. The higher the drivers of supply chain vulnerability, the higher the level of demand-side risk a firm faces.

- Supplier business risks relate to the various events that affect the continuity of the supplier and result in the temporary or permanent perturbation or termination of the buyer–supplier relationship. This concerns particularly the threat of financial instability of suppliers and the consequences of supplier default, insolvency, or bankruptcy (Wagner and Johnson, 2004).

H2. The higher the drivers of supply chain vulnerability, the higher the level of supply-side risk a firm faces.

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- In many regions of the world, natural hazards such as tsunamis, droughts, earthquakes, hurricanes, and floods are a constant threat to societies in general and to firms in particular (Helferich and Cook, 2002).

H3. The higher the drivers of supply chain vulnerability, the higher the level of catastrophic risk a firm faces.

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3. Methods

- **Data collection**

Data were collected through a cross-sectional questionnaire survey administered in Germany to a sample of 4946 top-level executives in logistics and supply chain management. The mailing and two follow-ups generated 760 usable responses, yielding a relatively high response rate of about 15.4%.

- **Sample**

A more detailed breakdown of the sample and informants can be found in Table 1.

- **Research method**

This study used structural equation model and five-point Likert scale.

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	Percent of total sample (%)	
Sector and industry		
<i>Industry sector</i>		71.5
Automotive	11.2	
Electro/electronics	10.1	
Machinery	9.5	
Chemicals and pharmaceutical	8.4	
Information technology	6.6	
Materials and metal production	6.2	
Food	5.5	
Paper, pulp, and printing	4.2	
Construction	3.0	
Consumer goods	2.5	
Aerospace and defence	2.1	
Medical devices	1.3	
Other industry	0.9	
<i>Service sector</i>		19.5
Logistics services	17.1	
Other services	2.4	
<i>Trade sector</i>		8.8
Sales (in US\$)		
Less than 10 million		14.9
10 million—under 50 million		23.9
50 million—under 100 million		16.3
100 million—under 250 million		14.7
250 million—under 500 million		8.7
500 million—under 1 billion		6.7
1 billion—under 10 billion		7.2
10 billion and more		5.0
n.a.		2.5
Number of employees		
Less than 100		21.4
100–499		42.2
500–999		11.6
1000–4999		15.3
5000–9999		2.8
10,000 and more		3.7
n.a.		3.0
Position of informant		
Logistics/supply chain management		37.5
C-level executives or owners		23.8
Purchasing/procurement		15.0
Production/operations		13.9
Sales, distribution, and service		3.6
Other senior management		3.4
Accounting/finance		2.1
n.a.		0.6

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● Summary of the Research Dimensions, Measurements and Questions

Table A1
Measures

Items (response cues)	Number of items	Cronbach's alpha	Factor loading	Item-to-total correlation
To what extent has your firm in the past 3 years experienced a negative impact in supply chain management due to ... (not at all—to a very large extent)				
<i>Demand side risks</i>				
Unanticipated or very volatile demand	2	0.724	0.879	0.568
Insufficient or distorted information from your customer about orders or demand quantities			0.821	0.568
<i>Supply side risks</i>				
Poor logistics performance of suppliers (e.g., delivery dependability, order fill capacity)	5	0.799	0.826	0.695
Supplier quality problems			0.787	0.687
Sudden demise of a supplier (e.g., due to bankruptcy)			0.725	0.550
Poor logistics performance of logistics service providers			0.684	0.504
Capacity fluctuations or shortages on the supply markets			0.516	0.478
<i>Catastrophic risks</i>				
Political instability, war, civil unrest, or other socio-political crises	4	0.854	0.858	0.756
International terror attacks (e.g., 2005 London or 2004 Madrid terror attacks)			0.817	0.672
Diseases or epidemics (e.g., SARS, foot and mouth disease)			0.806	0.672
Natural disasters (e.g., earthquake, flooding, extreme climate, tsunami)			0.799	0.684
Please evaluate the following statements: (strongly disagree—strongly agree)				
<i>Customer dependence</i>				
Our firm strongly depends on some of its customers	1			
<i>Supplier dependence</i>				
Our firm strongly depends on some of its suppliers	1			
<i>Supplier concentration</i>				
Our firm has concentrated its sourcing activities on a small number of suppliers	1			
<i>Single sourcing</i>				
Our firm frequently pursues single sourcing strategies	1			
<i>Global sourcing</i>				
Our firm relies on a global supplier network (global sourcing)	1			

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- All item-to-total correlations are above 0.5, i.e. have values greater than 0.35, a threshold that indicates that an item should be deleted from the scale. Cronbach's alpha coefficients range from 0.724 to 0.854. As a rule, coefficients above 0.6 are professionally acceptable, in particular for new scales. All items meet established standards for convergent validity, i.e. all items load on unique components with factor loadings larger than 0.5.
- 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.

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- For hypothesis testing analysis, summated composites of the multi-item measures were calculated. Correlations of constructs and descriptive statistics are summarised in Table 2.

Table 2
Summary statistics and correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Customer dependence	n.a.								
(2) Supplier dependence	0.25***	n.a.							
(3) Supplier concentration	0.10**	0.32***	n.a.						
(4) Single sourcing	0.13***	0.40***	0.31***	n.a.					
(5) Global sourcing	-0.15***	0.07*	-0.05	0.10**	n.a.				
(6) Demand-side risk	0.20***	0.18***	0.11**	0.12***	0.05	n.a.			
(7) Supply-side risk	0.04	0.26***	0.04	0.22***	0.21***	0.40***	n.a.		
(8) Catastrophic risk	0.02	-0.04	0.02	0.03	0.16***	0.13***	0.31***	n.a.	
(9) Firm size	-0.03	-0.00	-0.04	0.01	0.08*	-0.01	-0.00	0.02	n.a.
Mean	3.35	3.03	2.80	2.41	3.00	3.25	2.47	1.55	2.913
Standard deviation	1.27	1.23	1.11	1.14	1.37	0.99	0.77	0.73	19.104

***Significant at the 0.001 level.

**Significant at the 0.01 level.

*Significant at the 0.05 level.

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4. Results

Table 3
OLS regression results

	Dependent variables		
	Demand-side risk	Supply-side risk	Catastrophic risk
<i>Control variable</i>			
Firm size	-0.01	-0.02	0.01
<i>Predictor variables</i>			
Customer dependence	0.17***	0.00	0.05
Supplier dependence	0.10*	0.23***	-0.09*
Supplier concentration	0.06	-0.05	0.04
Single sourcing	0.05	0.13***	0.03
Global sourcing	0.07	0.18***	0.16***
Model summary	$F(701, 6) = 8.58^{***}$ $R^2 = 0.07$	$F(702, 6) = 16.83^{***}$ $R^2 = 0.13$	$F(701, 6) = 3.48^{**}$ $R^2 = 0.03$

***Significant at the 0.001 level.

**Significant at the 0.01 level.

*Significant at the 0.05 level.

- The outlined drivers of supply chain vulnerability explained 7% of the variance of demand-side risk ($F_{701, 6} = 8.58$). H1 posits a relationship between the drivers of supply chain vulnerability and demand-side risk. This is supported by two factors that significantly increase demand-side risk: strong customer dependence (standardised parameter estimate 0.17) and strong supplier dependence (0.10).

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- The drivers of supply chain vulnerability explained 13% of the variance of supply-side risk ($F_{1/4, 702, 6} = 16.83$). H2 positing that the identified drivers of vulnerability have a positive effect on supply-side risk was confirmed for supplier dependence (0.23), single sourcing (0.13), and global sourcing (0.18).

- The drivers of supply chain vulnerability explain solely 3% of the variance of catastrophic risks ($F_{1/4, 701, 6} = 3.48$). There is a highly significant positive relationship of a firm's reliance on a global sourcing network and the degree of catastrophic risk it experiences (0.16). This provides some support for H3.

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5. Conclusion

- Supply chain disruptions actually influence supply chain performance or firm performance.
- Concerning the first regression model, 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.
- 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.
- 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 argumentation also applies to single sourcing, the single sourcing approach seems to be less hazardous than general dependence on some suppliers. ¹⁵

- This study shows that global sourcing boosts particularly risk stemming from the upstream supply chain.
- It is solely global sourcing that is a significant factor that exposes firms to higher risk from catastrophes.
- This study shows that supplier dependence decreases the risk exposure to catastrophes.
- The findings from the three models provide support for the hypothesis that supply chain characteristics or design variables influence the exposure of the involved firms to the results from supply chain disruptions.

