UNIVERSITETET I AGDER

An empirical investigation into the sources of supply chain disruptions

Magne Lian and Petter Marki Erichsen

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SUPERVISORS
Prof. Omera Khan and Assoc. Prof. Stina Torjesen

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Faculty of Engineering and Science
School of Business and Law

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I. Preface

The main aim of this study has been to investigate what risks that have caused supply chain disruptions over the last decade. The study has been conducted as a part of the Master's programme in Industrial Economics and Technology Management at the University of Agder.

The original idea behind the study stems from Prof. Omera Khan and Assoc. Prof. Stina Torjesen who had a hunch that supply chain managers gave more importance to catastrophic risks such as terrorism and earthquakes, rather than the more mundane risks such as part shortages and transportation issues when assessing risks to their supply chains. In order to investigate if this notion corresponded with reality the authors, together with Prof. Khan and Assoc. Prof. Torjesen identified the need to carry out an in-depth analysis. This led to the authors conducting an extensive empirical study largely based on secondary data from the Financial Times on the sources behind supply chain disruptions.

The authors would like to thank Prof. Khan and Assoc. Prof. Torjesen for their valuable supervision along the way from the initial idea to the finished product. Also, the authors would like to thank Prof. Kevin B. Hendricks and Prof. Vinod R. Singhal who on request shared the search terms they used in their classical work on supply chain disruptions.

Grimstad, 24.05.2019

Magne Lian

Petter Marki Erichsen

II. Summary

Firms are facing a vast array of risks which can cause disruptions to the normal operation of their supply chains. Managers striving to prepare for and overcome these disruptions have a broad selection of literature and risk reports at their disposal when assessing risks to their supply chain. These risk reports and academic works provide differentiated and compelling answers to what are the most pressing risks to supply chains, but are they accurate?

This study aims at providing managers with an empirical foundation on what the main sources of supply chain disruptions have been the last decade by addressing the following research question:

What have been the main sources of supply chain disruptions over the last decade, and do observed patterns correspond with expectations put forward in the scholarly literature and the risk management communities?

Based on a content analysis of 11 504 articles from the Financial Times archive from 2009-2018, 445 articles describing sources of supply chain disruptions were retrieved. The samples were later analysed using statistical methods. The results of this investigation revealed that disruptions originating from within the supply chain were in sum the most prevalent. The majority of these disruptions were associated with risks that have traditionally been the concerns of supply chain managers. These risks include operational struggles at suppliers that are unable to deliver the desired quantity and quality, as well as challenges with forecasting demand and navigating the legal and bureaucratic process that emerge from operating a complex global supply chain across multiple regions. The study also revealed that supply chain disruptions stemming from risk sources external to the supply chain such as asset price collapse, natural hazards, terrorism and political turmoil have accounted for a relatively constant number of supply chain disruptions over the last decade. This observation is contrary to the seemingly increasing focus on these risks by the global community. However, even though there has not been an increase in disruptions caused by external events, catastrophic events still stood out as one of the biggest threats facing supply chains. Catastrophic incidents encompass high impact-low probability events including natural hazards such as earthquakes and hurricanes together with man-made acts both deliberate e.g. war and terrorism, and unintentional such as fires. Somewhat contrary to the attention given

to acts of terrorism in the wake of the 9/11 attacks, disruptions associated with acts of terrorism constituted a surprisingly small number of the supply chain disruptions, with the vast majority of disruptions related to catastrophic events attributed to natural hazards. Lastly, the findings showed that disruptions originating from risks associated with information and communication technology, in particular, cyber-crime and unplanned IT outage, have been an increasingly common source of supply chain disruptions during the decade in conjunction with the advancing digitalisation of supply chains.

Comparing the findings against the focus of academia and the risk management communities it is apparent that the strong focus on risks external to the supply chain is somewhat warranted given the frequent occurrences of catastrophic events that disrupt supply chains. However, the study revealed that too much attention has been given to these high-profile events, and in the process the more mundane risks facing supply chains have received less attention. As a consequence, these risks continue to pose a significant threat to the performance of supply chains. The findings highlight the importance of using several sources of information when assessing risks to supply chains. No single source of information, may it be scholarly literature, risk reports or internal reporting are able to grasp all the current, and future, patterns of supply chain disruptions by themselves. Managers should keep this in mind when identifying and assessing the risks to their supply chain. Diligence in seeking out alternative sources of information on supply chain risks can aid in creating a more advantageous supply chain risk management process and foster greater resilience in supply chains.

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1 Introduction

There is ample evidence of the potentially devastating effects of a supply chain disruption. In March 2000 a lightning strike hit a power line in Albuquerque, New Mexico. The strike caused a massive surge in the nearby electrical grid which in turn started a fire at a plant producing radio-frequency chips. Even though the fire was put out after only ten minutes, the damage resulted in a three-week shut down of production. Scandinavian mobile phone manufacturers Ericsson and Nokia were both customers of the plant. Nokia almost immediately began switching orders to other suppliers, whereas Ericsson had no contingency strategy. The outcome of the two firms was vastly different. Nokia suffered almost no loss from the disruption and went on to become one of the leading mobile-phone manufacturers of the decade. Ericsson, on the other hand, lost months of mobile phone production resulting in a $400 million loss which in the end contributed to Ericsson's withdrawal from the mobile phone business (Norrman and Jansson, 2004; Chopra and Sodhi, 2004).

The case of Ericsson shows how a disruption in the supply chain can result in a serious loss for the focal firm, even threating its existence. In a bid to mitigate the threats posed by supply chain disruptions, the concept of Supply risk management (SCRM) has garnered the attention of academics and practitioners a like in recent years (Ho, Zheng, Yildiz and Talluri, 2015). SCRM aims at avoiding, and reducing the consequences of, supply chain disruptions by identifying, assessing, treating and monitoring supply chain risks (Louis and Pagell, 2019). Given the importance of SCRM in dealing with supply chain disruptions, it is quite alarming that a large number of managers seem to neglect the importance of SCRM in their supply chain. In a study conducted amongst managers in the MIT Scale Network 60% of the respondents answered that they either do not work actively with managing supply chain risks, or do not consider their company's risk management effective (Sáenz and Revilla, 2014). The same pattern is revealed through a recent study by the Business Continuity Institute (BCI) on supply chain disruptions. Only 30% of firms surveyed conducted firmwide reporting on supply chain disruptions. Additionally, 62% of the respondents answered that their organization did not employ technology to predict, monitor, record and report on supply chain disruptions (BCI, 2018). This is somewhat of a paradox, knowing that a key part of SCRM is having accurate data on which risks to prepare for (Sheffi, 2005). The large number of managers who do not record on supply

chain disruptions implies that there are other sources of information such as literature and risk reports which are used when assessing risks to their supply chains. This observation stresses the importance of having accurate literature and risk reports on current and future patterns on the sources behind supply chain disruptions to base managers' risk assessment on. It is therefore quite remarkable that there seems to be a lack of large-scale empirical studies on supply chain disruptions (Sodhi, Son and Tang, 2012).

After the seminal efforts of Hendricks and Singhal (2003, 2005a, 2005b) and Wagner and Bode (2006, 2008, 2009) most studies seem to be either literature reviews, case studies or surveys limited in scope. In a survey among authors and practitioners, Sodhi et al. (2012) found that most agreed that there was a shortage of empirical research in the area of supply chain risk management, indicating a gap in the literature. Based on the observed literature gap, and the notion pointing towards managers relying on literature and risk reports when assessing risks to their supply chains this study aims to answer the following research question:

What have been the main sources of supply chain disruptions over the last decade, and do observed patterns correspond with expectations put forward in the scholarly literature and the risk management communities?

Given the core task facing managers of assessing risks to their supply chain and given that accurate knowledge of past disruptions forms an important part of the SCRM process, this study aims to investigate actual patterns of disruptions in supply chains. The authors believe insights from this study will alert managers to the potential discrepancies between commonly held views regarding supply chain disruptions and actual disruption patterns. This might inspire more vigilance in managers own tracing of empirical data on disruption patterns in their specific supply chains and help foster greater resilience in companies.

This study aims to provide novel contributions to the field of research in three ways. First by quantifying the most prominent sources of supply chain disruptions in terms of the number of disruptions using large scale empirical data other than surveys. Second by responding to the call for more empirical driven studies on supply chain risks put forward by Sodhi et al. (2012). Third by testing an established categorisation scheme on supply chain risks, and by doing so

contributing to the transition from a typology towards a taxonomy on supply chain risks (Louis and Pagell, 2019).

The study is structured in the following manner. *Chapter 2* is split into two parts which provide the theoretical foundation of the study. First, a nomenclature consisting of key terms used in this study is outlined. Next, a set of hypotheses are formulated based on a discussion on what has been the focus of academia and risk management communities concerning sources of supply chain disruptions. *Chapter 3* explains the methodological choices made, centred around how content analysis was used to collect the data and which statistical methods that were used to analyse the data. *Chapter 4* presents the results together with an analysis of the data to test for support for the hypotheses. *Chapter 5* discusses the result of the analysis in relation to the research question. Finally, *Chapter 6* concludes the study with a summary of the findings together with the academic and managerial implications of the study, as well as suggestions for further research.

2 Theory

In this chapter existing literature within the field of research and from risk management communities on topics relevant for the study are reviewed. Within the domain of supply chain management (SCM), there seems to be no agreement of the scope and definitions of key concepts (Ho et al., 2015; Wagner and Bode, 2006). An illustration of this lack of consensus can be found in the study of Ho et al. (2015). In a literature review on supply chain management, they found differences in the scope of supply chain risks from only including supply-side risks to encompassing risks to the supply chain in general. Consequently, the purpose of section 2.1 of this chapter will be to outline a consistent nomenclature suitable for this study. Section 2.2 will present an extract of what is to be found in literature and key risk publications on sources of supply chain disruptions. The chapter concludes with a set of hypotheses based on the literature review aimed at shedding light on the research question.

2.1 Nomenclature

Researchers and practitioners seem to have different opinions on the scope and definitions of key concepts (Ho et al., 2015). In order to code and analyse the empirical data consistently, the authors saw the need for an agreed set of definitions and terms. E.g. a lack of consensus on the scope of key concepts, such as the extent of a supply chain, would make the coding of data inconsistent between the authors limiting the reliability of the data. Current literature on key concepts was reviewed and definitions deemed suitable for this study were chosen.

2.1.1 Supply chain

Several definitions on a supply chain have been presented in the literature. The definitions vary in scope. Some adopt a narrow view by only looking at the process from the initial raw material to the finished goods consumed by the customer, whereas others define supply chain in a more holistic manner including the management of supply and demand (Lummus and Vokurka, 1999). In light of recent news on supply chain disruptions, e.g. how unexpected high demand for CO2 due to high consumption of beverages during the world cup in football caused a shortage of CO2 to stun pigs before slaughter (Daneshkhu, Buck and Dickie, 2018), the authors opt for the latter view of Lummus and Vokurka (1999). Quinn's (1997) presents a definition of a supply chain in line with this view.

> "All of those activities associated with moving goods from the raw-materials stage through to the end user. This includes sourcing and procurement, production scheduling, order processing, inventory management, transportation, warehousing, and customer service. Importantly, it also embodies the information systems so necessary to monitor all of those activities (Quinn, 1997)"

This definition includes the notion of the transformation process from raw materials to the finished goods together with activities related to operating a supply chain. As supply chain disruptions can originate both from difficulties in the transformation process including quality problems and from operational activities such as the inability to predict demand the authors finds Quinn's (1997) definition suitable to grasp the scope of possible sources of supply chain disruptions. By conferring to the definition of Quinn (1997), the authors believe the coding will be carried out consistently between the coders which will limit the number of ambiguous samples due to a lack of consensus on the extent of a supply chain.

2.1.2 Supply chain risk

Within SCM communities there seem to be a limited consensus regarding how to define the term supply chain risk (Rao and Goldsby, 2009). Researchers even debate the etymology of the word risk. Khan and Burnes (2007) suggest that the word stems from the Italian word *rissare* which means "to dare". Whereas other authors argue that the word derives from the Arabic word *risq* which translates to "gift from God" (Norrman and Lindroth, 2004). With a discrepancy in opinions regarding the origin of the word risk, there might be no surprise that there exist several definitions of supply chain risk within the literature. Some authors include both the potential downsides and the upsides caused by the variation from the expected outcome (Arrow, 1970). Other authors regard supply chain risk solely as something with a potential negative implication towards performance (Rao and Goldsby, 2009). Khan and Burnes (2007) explain this by pointing out that it is the downside rather than the upside that tend to occupy the mind of managers. For the purpose of this study, the interpretation of the term supply chain risk as something purely negative best corresponds to the research question which aims at investigating actual disruptions that have materialized into negative consequences for the firm. Thus, the authors follow Louis and Pagell's (2019) definition which is based on the work of Wagner and Bode (2006) and Tummala and Schoenherr (2011) when defining supply chain risk as "the unwanted negative

deviation from expected outcomes that can adversely affect supply chain operations and may result in detrimental consequences to a focal firm" (Louis and Pagell, 2019, p. 331).

2.1.3 Supply chain disruption

No common accepted definition of a supply chain disruption seems to exist. Tomlin (2006) use the term in the title of his study, *On the Value of Mitigation and Contingency Strategies for Managing Supply Chain Disruption Risks*, but do not provide an explicit definition, indicating that there might exist a tacit knowledge within the field of research on the definition of a supply chain disruption.

However, other authors provide a definition. Wagner and Bode (2006) define it as "An unintended, untoward situation, which leads to supply chain risk. For the affected firms, it is an exceptional and anomalous situation in comparison to every-day business" (Wagner and Bode, 2006, p. 303). This definition looks at supply chain disruption as an event which leads to risk, not a situation which materializes into negative consequences for the firm. In their later study Wagner and Bode (2008) refine their definition when they define a supply chain disruption as "The combination of (1) an unintended , anomalous triggering event that materializes somewhere in the supply chain or its environment, and (2) a consequential situation which is significantly threatens normal business operation of the firms of in the supply chain"(Wagner and Bode, 2008, p. 309). This later definition looks at supply disruption as something more than an event which leads to risk, but a situation that might threaten the normal operation of the business, and thus the potential for a loss.

Even though this latter definition is broader than the first, it lacks the notion of a source behind the disruptions making it less useful for a broader audience. Parast and Shekarian (2019) builds on the work of Wagner and Bode (2006, 2008) when they define a supply chain disruption as "the occurrence of unpredictable and undesirable events such as natural disasters, loss of partnership relationships, and changes in customer preferences which undermine supply chain performance"(Parast and Shekerian, 2019, p. 367). This definition includes sources of supply chain disruptions along several dimensions of risks and incorporates the negative consequences of supply chain disruptions. This aligns with what the authors expect to find when searching the Financial Times archive where mainly disruptions that have caused negative consequences for the firm is likely to be mentioned. Therefore, the authors believe that the definition of Parast and

Shekerian (2019) will contribute to a consistent coding of the data from the Financial Times archive concerning supply chain disruptions.

2.1.4 Supply chain risk categorisation

The need for a common risk categorisation scheme has been addressed by several authors (Rao and Goldsby, 2009; Ho, et al., 2015; Louis and Pagell, 2019). According to Ho. et al. (2015) no clear consensus exists, even though several authors have proposed categorisation schemes which to a degree overlap.

Louis and Pagell (2019) analysed current literature with a systematic literature network analysis method to find the most influential studies dealing with supply chain risk categorisation. Their findings were based on global citation count and a closeness/centrality score which denotes how often the article has been cited within the network. The analysis showed that 15 articles stood out as the most influential. Subsequently, a main path analysis of the 15 articles was applied to trace important milestones in the development of classifications schemes. The analysis revealed that the development can be divided into three distinct stages.

The first stage (2000-2004) saw the first development of classifications schemes that divided between risk factors internal and external to the supply chain. Christopher and Peck (2004) categorized risk factors into supply risk, process risk, demand risk, control risk and environmental risk, establishing a framework which explicitly addressed disruptive events such as natural disasters.

The second stage (2005-2012) contributed with further understanding of network risk sources and how all firms along the supply chain were exposed to risks in the supply chain (Louis and Pagell, 2019). Wagner and Bode (2006, 2008) added a new category, catastrophic events, which separate from Christopher and Pecks's (2004) environmental risks by looking exclusively at rare but severe events external to the supply chain, e.g. the 9/11 terrorist attack.

The third stage (2013-2016) saw the work of Ho et.al (2015) and Dong and Cooper (2016). Both provide more systematic efforts to categorize supply chain risks. While Ho et.al (2015) offers a categorizing using the systematic literature review method, Dong and Cooper (2016) use existing categorizing schemes but apply an order-of-magnitude approach to assess probability and impact of different risk factors.

Based on their analysis Louis and Pagell (2019) propose a categorisation scheme that incorporates the most influential earlier work aiming to contribute to a consensus among researcher within the field. The categorisation scheme is comprehensive and covers several aspects of supply chain risks that have been proposed over the years. As one of the aims of this study is to gain insight into the sources of supply chain disruptions, using a categorisation scheme based on previous developments within the field allows for the use of terms that are established and recognisable. Using previously established terms contributes to a meaningful comparison between the views put forward in literature and the risk management communities and the acquired data. Additionally, by using the categorisation scheme this study might contribute to the development of taxonomies of supply chain risk. Louis and Pagell (2019) remark in their study that there exist numerous typologies of supply chain risk, but that there has been limited research using empirical methods to develop taxonomies. Using their categorisation scheme in an empirical investigation might serve as a step towards this development.

2.1.4.1 Louis and Pagell's categorisation scheme for supply chain risk

Louis and Pagell (2019) divide risk factors into 23 different sub-categories under the following three main-categories; Risks *external to the supply chain*, risks *internal to the supply chain* and risks *internal to the firm* as displayed in table 1.

Table 1**:** Supply chain risk categorisation scheme. Adapted from Louis and Pagell (2019).

Risks external to the supply chain	Risks internal to the supply chain	Risks internal to the firm
Competitiveness	Supplier operational	Infrastructure
Input market	Supplier economic	Strategic
Political risk	Cultural	Problem-specific
Catastrophic	Relational	Decision-maker specific
Financial market	Demand	Reputation
	Transportation	Capacity
	Inventory	Financial capacity (receivables)
	Legal, bureaucratic and regulatory	
	Sustainability	
	Financial capacity (Receivables)	
	Consumer risk	

The categorisation scheme is viewed from the perspective of a focal firm within the supply chain and addresses supply chain risks that are considered to originate from the firm itself, risks that stem from interaction between the actors within the supply chain and risks that are outside the boundaries of the supply chain (Louis and Pagell, 2019). For the purpose of clarity and a better

understanding of the categorisation scheme, the three main-categories are explained in more detail below including examples of supply chain disruptions that can be associated with each main-category. For a comprehensive version including definitions and detailed descriptions of each sub-category see appendix A.

2.1.4.1.1 Risks external to the supply chain

Risk *external to the supply chain* arises from events outside of the supply chain. Such episodes encompass dramatic changes in the political system as seen in the recent trade war between the USA and China, catastrophic events such as earthquakes and various macro-economic factors including changes in exchanges rates, inflation and interest rates (Louis and Pagell,2019). An example of a disruptive event that can be placed in this category is the Egyptian currency crisis and its impact on wheat supplies. In 2013 Egypt was forced to reduce its import of grains due to increases in the exchange rate between the Egyptian pound and US dollars reducing the country´s grain stocks (Terazono and Saleh, 2013).

2.1.4.1.2 Risks internal to the supply chain

Risks *internal to the supply chain* encompasses risk sources that have traditionally been of concern for supply chain managers in the form of supply- and demand side risks (Wagner and Bode, 2009). These risks include challenges with predicting demand, suppliers that are unable to deliver the necessary quantity and/or quality and unwanted events that delay the movement of materials such as port strikes, carrier breakdown and other failures in the distribution network. In addition to the traditional concerns of transportation, supply and demand this category also focus on more elusive risks such as risk arising from mistrust among actors, challenges with fulfilling customer preferences and the legal and bureaucratic woes facing modern supply chains (Louis and Pagell, 2019).

Events that transpired at Kentucky Fried Chicken (KFC) in the UK is an example that demonstrates how risk sources *internal to the supply chain* can have a significant negative impact on the performance of a firms supply chain. In 2018 KFC was forced to temporarily shut down 900 of their UK restaurants due to operational issues with their new transport provider DHL that prevented the delivery of chickens from their only UK warehouse (Dye, 2018). Another fast food related example is MacDonald’s Japan shortage of fries due to labour disputes at US ports (Inagaki, 2014). Outside the realm of fast-food, Nanocos a provider of quantum dots

for use in LCD TVs by LG experienced a delay in their supply chain on account of LG changing their preference and demanding the appliance of a different substrate for the dots, as well as only accepting production from South Korea (Bounds, 2015).

2.1.4.1.3 Risks internal to the firm

Risks *internal to the firm* is concerned with risk factors within the focal firm that can have an impact on the successful execution of the firm's supply chain. Risks *internal to the firm* include failures related to infrastructure such as IT systems and vehicles, challenges with the utilization of production capacity as well as events that that might negatively impact the firm's ability to execute their business strategy. Intel's forced delay to full production by three months illustrates the risk associated with capacity as they struggled to increase yields of new processor chips on a smaller fabrication node (Waters, 2013). Another example of a disruption that can be associated with risks *internal to the firm* is the case of retail group Kingfisher. Kingfisher experienced disruptions to their supply chain that in part was caused by the inability to implement their "One Kingfisher" restructuring plan that intended to simplify supply lines and reduce complexity (Khan, 2017).

This section has focused on developing a consistent nomenclature for this study including a supply chain risk categorization scheme. Section 2.2 will utilize this as a framework to explore common views on sources of supply chain disruptions put forward in academia and risk management communities.

2.2 Sources of supply chain disruptions

Throughout the last decades, in conjunction with the emergence of supply chain risk management (SCRM), there have been numerous inquiries into the sources behind supply chain disruptions (Louis and Pagell, 2019). SCRM typical follows a process of identification, assessment, treatment and monitoring of supply chain risks (Louis and Pagell, 2019). Following this structure, it is apparent that after identifying risks it is paramount to assess the relative importance of the different risks in order to inform the subsequent processes on which risks are most likely to pose a threat to the supply chain (Jüttner, Peck and Christopher, 2003).

Given the importance of accurate risk assessment for the SCRM process, this has naturally become a topic of interest amongst academic as well as risk management communities. Different

attempts at assessing risks to supply chains have been carried out from various academics and organizations such as the World Economic Forum (WEF) and the Business Continuity Institute (BCI). This section aims to explore some of these attempts in order to gain insight into the views of academics and the risk management communities on the key risk sources causing supply chain disruptions. As one of the central goals of this study is to investigate how the acquired data corresponds with expectations put forward by academia and the risk management communities, the findings from the literature review is used to develop a set of hypotheses for testing.

The section is structured in the following manner. First, the sentiment that risks *external to the supply chain* have increased in tandem with globalization of supply chains is explored. Next, attention is given to *catastrophic* risks which have been brought to the forefront by high profile events such as the 9/11 terrorist attack and the Great East Japanese earthquake of 2011. Then focus is given to risks *internal to the supply chain* and the proposition that despite the attention given to high impact external events, disruptions originating from within the supply chain are still the most common. Finally, driven by the growing dependence on information and communication technology (ICT), *infrastructure* risk is addressed as an increasingly dominant source of supply chain disruptions.

2.2.1 Risks external to the supply chain as a source of supply chain disruptions

Risks *external to the supply chain* have gained considerable attention from academics and practitioners as a source of supply chain disruptions over the last decades (Barry, 2004; Manuj and Mentzer, 2008; Wagner and Neshat N., 2009; Jüttner and Maklan, 2011; Tang and Musa, 2011). Researchers argue that global supply chains are inherently riskier than the domestic supply chains of the past, due to the numerous links interconnecting an extensive network of firms (Manuj and Mentzer, 2008). Risk factors include *competitiveness* in the market place, challenges with sourcing raw materials from the *input marke*t, *political risk*, *financial market* risk and *catastrophic* events, such as earthquakes and terrorism (Louis and Pagell, 2019). Numerous examples of supply chain disruptions that have occurred over the last decade can be traced back to external factors. These events cover aspects from shifting political agendas and financial recession, to severe natural catastrophes such as earthquakes and acts of terrorism and war (Davarzani, Zanjirani, and Rahmandad, 2015). The financial crisis of 2008 resulted in an

international decline in demand and a high number of supplier insolvencies as a consequence (Jüttner and Maklan, 2011). The Libyan revolution overthrowing Colonel Muammar Gaddafi caused a serious fuel shortage in the oil-producing country (Peel, 2011). Floods and earthquakes in Asia such as the 2011 flood in Thailand and the Great East Japanese earthquake the same year led to part shortages for major firms such as Honda and Toyota (Reed, 2011). The last decade has even seen the rise of piracy as a threat with attacks along the horn of Africa impacting maritime supply chains (Sullivan, 2010).

An external risk factor that has gained considerable interest in recent times has been political risk (Smith, 2019). During the cold war the line between adversaries and allies was clearly defined and security- and trade policies were more sharply delineated (Rice and Zegart, 2018). Today's political landscape is significantly more complex and uncertain with rising states, declining sates, failed states and nonstate actors all influencing the global political landscape. Security is no longer a separate issue but have become increasingly interwoven with trade policies and economic issues (Rice and Zegart, 2018). As a result of these progressively rapid shifts in political ties, and the increased complexity of the political environment, the political risk towards supply chains have become a growing concern for businesses (Smith, 2019). Companies have extended their supply chains globally in order to improve their margin, but these longer and leaner supply chains have become more vulnerable to disruptions from external forces including political actions (Rice and Zegart, 2018).

Political risk to supply chains can manifest itself in numerous ways including trade tariffs, quota restriction and changes in taxation (Louis and Pagell, 2019). Recent events such as Brexit and the estranged relationship between the USA and China provides telling examples of this. The tension between the USA and China have led to tariff increases and import delays impacting the supply chain of firms ranging from care manufactures to pet food producers (Mitchell et al., 2018). In relation to Brexit, several UK based firms have been forced to increase their stockpiling of goods in a bid to prepare for trade stoppage (Bounds, 2018). Another political risk factor that have gained the attention of firms in the hyperconnected world of smartphones and the internet is social activism (Rice and Zegart, 2018). In 2017 South Korean carmaker Hyundai Motor Company reported a fall in sales of two-thirds year over year in China due to boycott from

Chinese customers over the deployment of a US owned anti-missiles system in South Korea (Lex, 2017).

In recent studies, the disruptive properties that political risks can have on supply chains have been explored further by looking at the concept of economical-political sanctions and their impact on supply chains. Sanctions imposed on countries by major international actors such as EU, UN and USA have the potential to disrupt supply chains in various ways including restriction on logistics, changes in regulations and changes in the business environment (Davarzani et al., 2015). An example of this is the US government's decision to reimpose sanctions against Iran which saw Boeings $20 billion contract for the delivery of aircraft to Iran frozen as aircraft sales were banned under the renewed sanctions (Crooks and Fleming, 2018).

The impact external forces can have one supply chains have gained substantial interest not only from the academic world but also from the broader business risk community including organizations such as the WEF. WEF in their report *New model for addressing supply chain and Transpiration risk* outlined the increased risk of disruption from external factors as supply chains have become more globalized (WEF, 2012a). In the report, 55 individuals from a diverse set of backgrounds rated the risks they believed to be most likely to cause disruptions to supply chains (Figure 1). The survey showed that risks stemming from environmental factors such as natural disasters and extreme weather, geopolitical factors including conflict and political unrest, and economic factors such as sudden demand shock were rated as the most likely to disrupt supply chains (WEF, 2012a). WEF (2013a) followed this effort to outline the major threats to supply chains with their *Building Resilience in Supply Chain* report further shedding light on the risk external forces poses to global supply chains. The survey conducted in 2012 showed that participants continued to consider natural disasters, conflict and political unrest, sudden demand shock and terrorism to be areas of concern for businesses.

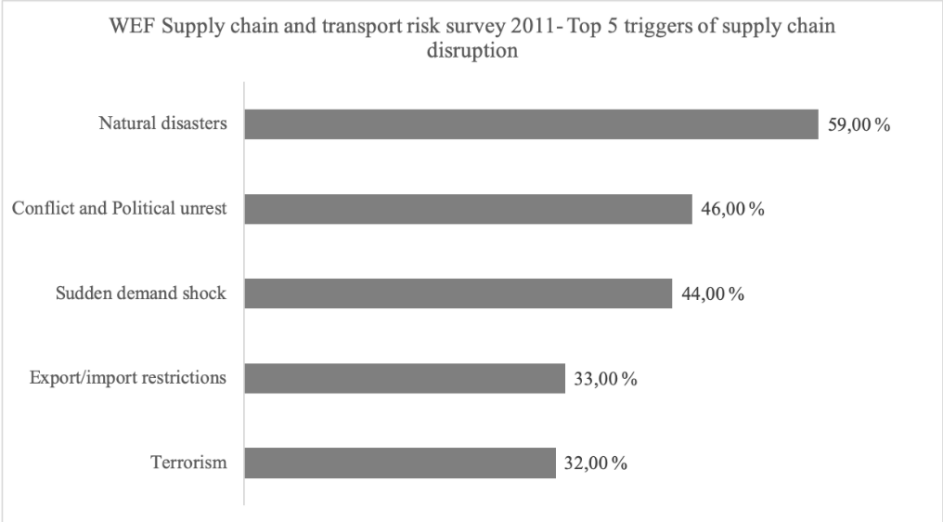

Figure 1**:** Top 5 triggers of supply chain disruptions. Source: World Economic Forum (2011) *New Models for Addressing Supply Chain and Transport Risk.*

In a more recent white paper describing the new world of economic coercion in an increasingly interconnected world, the WEF (2016a) further addressed the impact the political system has had on supply chains. In the report, WEF argues that supply chains have become economic battlegrounds for states in a bid to maintain their economic advantage. Governments use taxes and trade processes as means to manipulate supply chains for their own benefit, applying both carrot and stick tactics interchangeably. Import/export ban is another measure that has been utilized as demonstrated in the case of China`s sudden export ban on rare earth minerals to Japan in 2011-2012 (Khanna and Mitachi, 2016).

Risks *external to the supply chain* have also gained the attention of the BCI in their annual *Supply Chain Resilience Report*. The report is based on a survey among managers and supply chain managers where the respondents were asked to score if a set of predefined threats have caused any disruptions to their supply chain during the past 12 months (BCI, 2018). External risks including, adverse weather, currency exchange rate volatility, acts of terrorism, civil unrest, war and earthquakes/tsunamis have featured prominently through the years as significant sources of supply chain disruptions (BCI, 2009-2019).

The risk that external factors pose to supply chain as displayed by the WEF and the BCI is further amended by a recent report from Resillience360 on an initiative from DHL. Resilience360 reviewed the supply chain risk landscape for 2018 (Figure 2) and found that a

substantial amount of supply chain disruption could be traced back to by external factors including civil unrest such as the demonstrations in France, fires at industrial sites and natural disasters (Resilience360, 2019).

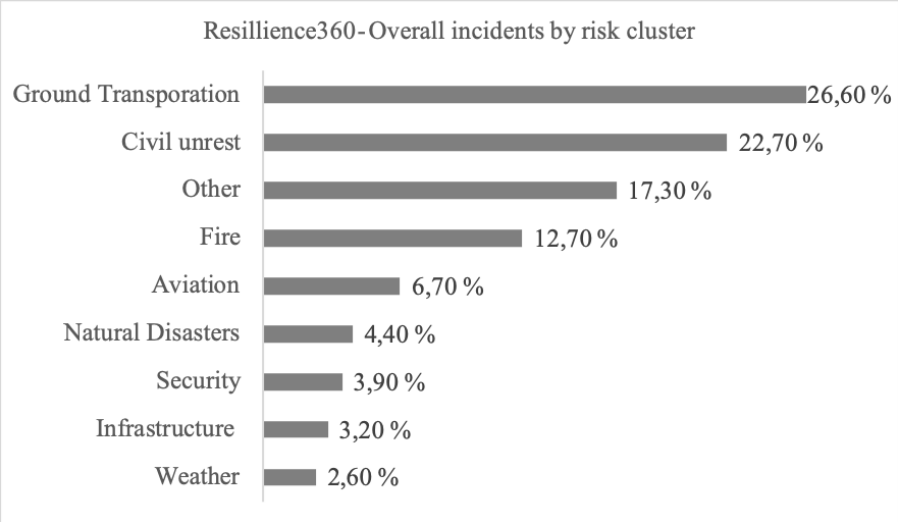

Figure 2: Supply chain risk landscape 2018. Source: Reslience360 (2019) *Reslience360 annual risk report 2018.*

Given the above-mentioned insights it could be argued that the global nature of modern supply chains in combination with a world that is more complex and uncertain have left them increasingly vulnerable to external risk factors. Not only from catastrophic event such natural disasters, but also from fallouts of the political and economic interplay between stats. The following hypothesis is therefore formulated.

H_1: *Risks external to the supply chain have increased as a source of supply chain disruptions during the last decade.*

2.2.2 Catastrophic risks as a source of supply chain disruptions

Dwelling on risks *external to the supply chain* as sources of supply chain disruptions a category that has garnered considerable attention has been natural or man-made disasters such as earthquake and terrorist attacks. (Sheffi, 2001). A striking example is the 9/11 terrorist attack on the twin towers in 2001. The 9/11 attacks caused airports to shut down which in turn led to major disruptions to the supply chain of firms including Ford and Toyota which were reliant on a continuous flow of material due to their Just-In-Time (JIT) manufacturing principles with a minimal inventory of materials (Sheffi, 2001). This focus on catastrophic events as a source of

supply chain disruptions has gained considerable traction during the last decades with researchers arguing that in the quest for cost reduction and efficiency, modern supply chains have become increasingly susceptible to disruptions from man-made and natural catastrophes (Wagner and Bode, 2006).

Literature has presented several key factors that have contributed to the increased vulnerability, including an increase in exposure points, lack of flexibility and limited redundancy (Stecke and Kumar, 2009). The increase in exposures points stems from the global nature of supply chains where goods are transported across geographical and political regions by various means of transportation which in turn increases exposure to disruptive events. The lack of flexibility comes from the utilization of few or single suppliers making firms reliant on materials from a single source. The lack of redundancy can in part be attributed to the implementation of JIT and Lean principles which have made firms dependent on an uninterrupted flow of materials due to a lack of inventory (Stecke and Kumar, 2009).

The risk catastrophic events pose to the supply chain has also gained a significant amount of attention amongst organisations such as the WEF. WEF found in their *Supply Chain and Transport Risk Survey* conducted in 2011 that 59% of the respondents (Figure 1) considered natural disasters including earthquakes and tsunamis the most significant external source of supply chain disruptions (WEF, 2012a). WEF followed up the 2011 survey with a survey in 2012 where natural catastrophes once again were considered the most significant external source of supply chain disruptions. Natural catastrophes were then followed by extreme weather such as droughts, conflict, political unrest and terrorism (WEF, 2013a).

The credence given to catastrophic events as major concerns for businesses is further bolstered by the attention given to such events in what might be considered the WEF´s flagship report, the *Global Risk Report* which has been issued annually since 2006. The *Global Risk Repor*t is based on a survey among members of the World Economic Forum's global multi-stakeholder community. The respondents are asked to rate a predefined set of risks factors which are determined by the WEF risk experts through a qualitative assessment on what will be the most predominant risk patterns the next decade (WEF, 2018) The reports have not been aimed specifically at predicting risks to supply chains, but there is evidence that suggests the reports have been used throughout the years extensively to inform risk managers and business

governance on future risk patterns (Aven and Cox, 2016). Supply chains being a vital part of a firm, there is a reason to believe that the *Global risk reports* are being used as a foundation for managers to assess risks to their supply chain. Reviewing "The Evolving Risk Landscape" in table 2, which looks at how the predicted risks in the *Global Risk Report* have evolved from 2009-2018, c*atastrophic* risks like "extreme weather events" and "natural disasters" have been featured prominently in the top 3 in terms of likelihood during the last decade. Particularly, weather- related risks have been given considerable attention during the last half of the decade in tandem with the growing concerns over climate changes (WEF, 2018).

Table 2: Global risk in terms of likelihood. Excerpt from the Global Risks report 2018. By World Economic Forum (2018).

Rank	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1st	Asset price collapse	Asset price collapse	Storm and cyclones	Severe income disparity	Severe income disparity	Income disparity	Interstate conflict with regional consequences	Large scale involuntary migration	Extreme weather events	Extreme weather events
2nd	Slowing Chinese economy	Slowing Chinese economy	Flooding	Chronic fiscal imbalances	Chronic fiscal imbalances	Extreme weather events	Extreme weather events	Extreme weather events	Large scale involuntary migration	Natural disasters
3rd	Chronic disease	Chronic disease	Corruption	Rising greenhouse gas emissions	Rising greenhouse gas emissions	Unemployment and underemployment	Failure of climate-change mitigation and adoption	Failure of climate-change mitigation and adoption	Major natural disasters	Cyberattacks

The considerable attention given to *catastrophic* events as a source of supply chain disruptions by the academic world and stakeholders from the WEF is not unwarranted. Wagner and Neshat (2009) argue that the increase in occurrences and intensity of natural and man-made disasters have contributed to the vulnerability of supply chains. In their study, Wagner and Neshat (2009) investigated the EM-Dat database managed by the Centre for Research on the Epidemiology of Disasters from 1940 until 2008 and found that the occurrences of disasters have increased dramatically over the decades. Appending the dataset to include data from 2008-2018 (Figure 3) shows a substantial growth that peaked between 2000-2009 with 7581 accounts of man-made

disasters and 7442 natural disasters. From 2010 -2018 the data shows that there has been a decline, but the number of occurrences nevertheless have been substantial with 4625 accounts of man-made disasters and 4898 natural disasters.

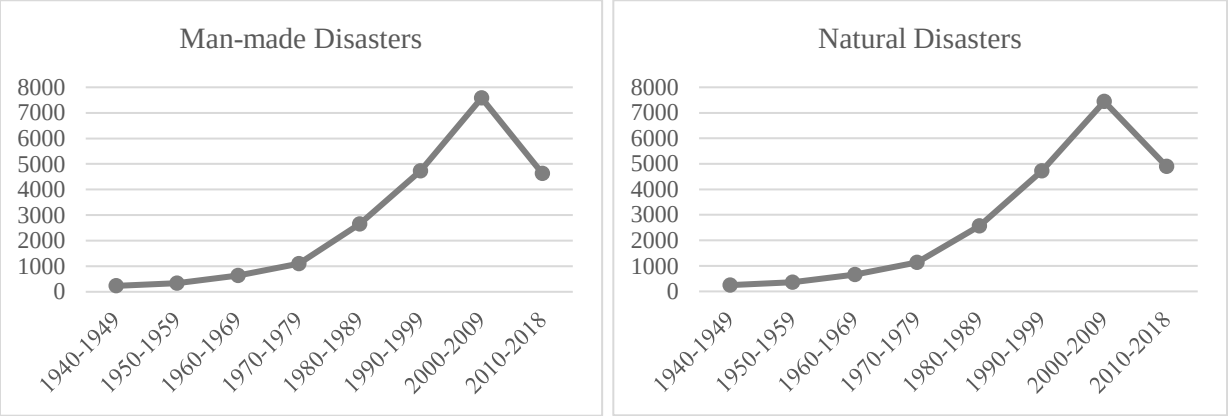

Figure 3: Natural and man-made disasters 1940-2018. Source: Centre for Research on the Epidemiology of Disasters (2019).

Numerous examples of catastrophic events have emerged throughout the years. In 2016 a major earthquake in southern Japan brought the manufacturing industry to a halt in the region. Firms such as Sony, Honda and Toyota were forced to stop production and initiate contingency plans (Harding, Inagaki and Lewis, 2016). Despite being well prepared and having implemented measures such as reinforcements of factories and alternative suppliers the impact on the supply chain was substantial with Toyota being forced to shut down car production due to a shortage of parts from suppliers in the region (Harding et al., 2016). The earthquake was considered the worst since the infamous earthquake in 2011 where researchers calculated that as much as 90% of the output loss from the earthquake could be considered caused by supply chain disruptions (Todo, Nakajima and Matous, 2015).

Another striking example is the havoc caused by the hurricane Floyd in North Caroline which flooded a Chrysler plant and forced the shutdown of seven assembly plants across North America (Güller and Henke, 2019). Events such as these highlights the vulnerability of complex supply chains even for the well-prepared actors that have implemented mitigation efforts.

The frequent occurrences of natural and man-made disasters in combination with the increased vulnerability of complex global supply chains suggest that *catastrophic* risks to the supply chain have been a prevalent source of disruptions during the last decade. The following hypothesis is therefore formulated.

H_2: *Catastrophic risks have been the most predominant source of supply chain disruptions during the last decade.*

2.2.3 Risks internal to the supply chain as a source of supply chain disruptions

Although, catastrophic risks have received a substantial amount of attention there are researchers that argue that more common events such as late deliveries, often associated with risks *internal to the supply chain*, pose just as much of a threat to supply chains (Stauffer, 2003). These risks are often considered mundane compared to the more headline-grabbing catastrophic risks and therefore often overlooked by managers despite the significant friction they can cause to supply chains (Stauffer, 2003).

In addition to the tendency to overlook these more common risks researcher argue that supply chains are more vulnerable than ever before if an event outside normal operations occurs (Stecke and Kumar, 2009). Whereas in the past production was relatively straight forward with a simple flow of materials from input to market, today's shorter product cycles and increased demand have led to heightened cost pressure and competition on the global stage (Tang and Musa, 2011). This has caused companies to adopt cost-efficient supply chain principles such as Just-in-Time material flow and lean production which promotes reductions in inventory and the number of suppliers (Tang and Musa, 2011; Stauffer, 2003). These strategies have helped to smooth out daily operations but left supply chains open to disruptions from risk sources both external and internal to the supply chain (Tang and Musa, 2011).

Examples of disruptions caused by internal sources are abundant. In 2013 Samsung experienced a shortage of Galaxy S4 due to higher than expected demand (Song, 2013). The same year mining company Rio Tino was unable to ship copper concentrate from their Oyu Tolgoi mine in Mongolia into China due to a bureaucratic hold up at the border lasting three months (Lucy,

2013). Another example is Airbus and Boeing struggling to deliver aircraft due to repeated production issues at engine manufacturer Rolls-Royce. (Cotterill, 2010; Pfeifer, 2018).

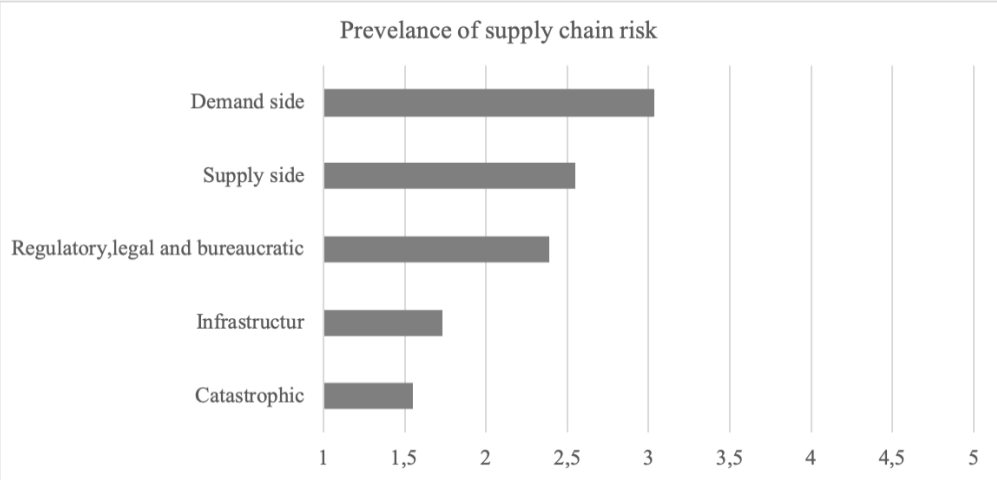

Figure 4: Prevalence of supply chain risk. Derived from "Dominant risks and risk management practices in supply chains." By Wagner, S. M., & Bode, C. (2009). In Supply chain risk (pp. 271-290). Springer, Boston, MA.

The notion of internal risk factors as a significant source of supply chain disruption is further asserted by Wagner and Bode (2009) which conducted a survey in Germany among 760 top-level executives in logistics and supply chain management. The survey indicated that risks considered *internal to the supply* chain have been the most prevalent. Respondents were asked to indicate how their business had been affected negatively during the last three years by five pre-selected categories of supply chain risk on a scale from 1- not at all to 5-to a very large degree (Figure 4). The risk category considered the most prevalent among the respondents was demand-side which includes unannounced and volatile customer demand, lack of information and bad payment behaviour from customers. Supply-side risks emerged in second place including events such as price fluctuations, supplier quality issues, capacity fluctuation, poor logistical performance from suppliers and abrupt supplier insolvencies. *Catastrophic* risks were considered the least prevalent category with the authors arguing that this was in rather stark contrast with the increased interest given to catastrophic risk. Wagner and Bode (2009) recognised that this might be attributed to the geographical limitation of the survey. Germany during the timeframe of the survey could be considered a somewhat stable business environment largely sheltered from *catastrophic* events. However, they also noted that the supply chains reported in the survey were not predominantly domestic and as such events in other regions would still have an impact on the firms surveyed (Wagner and Bode, 2009).

Risks *internal to the supply chain* as a source of disruption have also garnered considerable attention from academics. Ho et al. (2015) found in a literature review of international journal articles that demand, manufacturing and supply where the risk categories that have attracted the most attention. The findings of Ho et al. (2015) are supported by a recent survey conducted by Donadoni et al. (2019). Dondoni et al. (2019) surveyed academic experts to gain insights into what they considered to be the key supply chain disruptions. The 23 respondents considered disruptions associated with risks *internal to the supply chains* to be the most pressing, including network issues such as transportation, supplier insolvencies, challenges with forecasting demand, inability to comply with customer requirements and quality incidents.

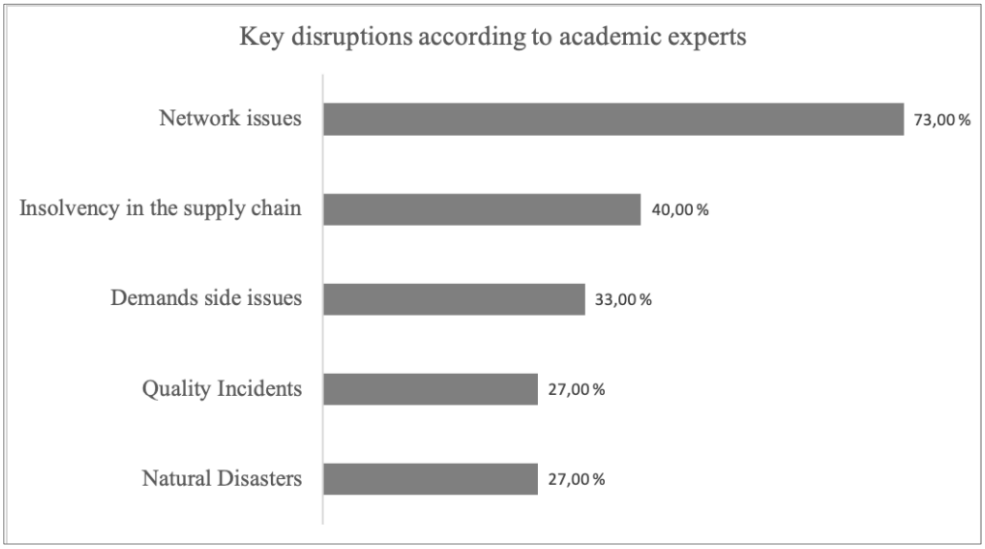

Figure 5: Key sources of supply chain disruptions according to academic experts. Derived from "The Future of Resilient Supply Chains". By Donadoni, M., Roden, S., Scholten, K., Stevenson, M., Caniato, F., van Donk, D. P., & Wieland, A. (2019). In Zsidisin G., Henke M. (Eds.), Revisiting Supply Chain Risk. Springer Series in Supply Chain Management.

In addition to the panel of academic experts Donadoni et al. (2019) carried out a survey among 43 European practitioners considered specialists in the field. The specialists were asked to rank the supply chain disruptions considered the most pressing by the academic experts on a seven-point scale in term of their relevance to their organization (1- being the most important and 7- the least important). The practitioners considered quality incidents as the most pressing cause of supply chain disruptions. Quality issues were then followed by demand with respondents citing fears of demand fluctuations. The third most pressing disruption was considered to be related to network risk encompassing problems with material flows in the physical supply chain such as transportation delays when importing products from across Europe. The least amount of attention

was given to natural disasters contrary to a lot of supply chain literature (Donadoni et al., 2019). This insight suggests that practitioners are more focused on supply chain risk factors that occur on a daily basis rather than catastrophic events (Donadoni et al., 2019).

Figure 6: Supply chain disruptions feared by practitioners. Derived from "The Future of Resilient Supply Chains". By Donadoni, M., Roden, S., Scholten, K., Stevenson, M., Caniato, F., van Donk, D. P., & Wieland, A. (2019). In Zsidisin G., Henke M. (Eds.), Revisiting Supply Chain Risk. Springer Series in Supply Chain Management.

This observation might indicate that despite the attention given to risks *external to the supply chain* and in particular catastrophic events, the more common issues associated with risks *internal to the supply chain*, often described as the "bread-and-butter" issues of supply chain management, have been the most prevalent sources of supply chain disruptions (Wagner and Bode, 2009). Based on these assessments the following hypothesis is formulated.

H_3: *Risks internal to the supply chain have been the most common source of supply chain disruptions during the last decade.*

2.2.4 Infrastructure risks as a source of supply chain disruptions

The advent of global Information and Communications Technologies (ICT) has brought numerous advantages to companies, such as the benefits from online management of the flow of goods and demand assessment, aiding them in managing their supply chain more effectively (Warren and Hutchinson, 2000).

However, this increased use of ICT, especially the internet, has also brought with it a dark side which early on gained considerable attention from academia. Researchers argue that the

dependency on ICT comes with a plethora of risks that represent tremendous challenges to the successful execution of supply chain operations (Warren and Hutchinson, 2000). Perhaps the most notable of these risks is the threat of cyber-crime such as viruses, denial of service and hacking (Warren and Hutchinson, 2000).

Over the last decade, this dependency on ICT systems has increased substantially with a majority of areas related to business reliant on various ICT systems (Linton, Boyson and Aje, 2014). This reliance on ICT has also extended to supply chains with an increased proliferation of complex resource planning and communication systems across all aspects of the supply chain ranging from forecasting to production and distribution (Khan and Estay, 2015). This increased connectedness and digitalisation of supply chain processes have led to the emergence of what researchers describe as cyber-supply chains where cyberspace permutates all aspects of the supply chain from end-to-end (Colicchia, Creazza and Menachof, 2019). This has also brought with it a vast array of potential disruptive vectors towards supply chains not just from malicious external forces such as hackers, but also from hardware and software defects (Mensah and Merkuryev, 2014).

Researchers have argued that despite the increased reliance on ICT infrastructure and the severe economic impact disruptions to this infrastructure can have, managers have a tendency to underestimate the risk that the cyber-domain pose to their operations (Khan and Estay, 2015). In a recent study on cyber risks De Smidt and Botzen (2018) found that even though managers seem to recognize that their organization is exposed to risk from the cyber-domain, they tend to underestimate the financial impact of cyberattacks. Despite that managers seem to underestimate the financial consequences of risks stemming from the cyber domain, there is evidence that managers' awareness of these risks have increased over the last decades. A report released by McKinsey in 2017 showed that 75% of the informants considered cybersecurity a top priority for their business (McKinsey&Company, 2018). This tendency towards increased awareness is further bolstered by the display of cyberattacks and data theft rated by practitioners and managers as one of the top 5 risk from 2012-2018 in terms of perceived likelihood in the *Global risk report* (WEF, 2018).

However, the ability to transform this awareness into preventive actions might be considered limited as it was also noted that only 16% of firms considered themselves to be well prepared to

handle cyber risk (McKinsey&Company, 2018). This lack of preparedness might be attributed to the many managerial challenges such as regulatory and compliance issues facing businesses that utilised different ICT system with divergent standards and technologies (Urciuoli, 2015). The challenges facing firms when handling cyber- risk against their supply chains are reflected in a series of surveys conduce by the BCI for their annual S*upply Chain Resilience Report.* Participants in the surveys were asked to choose among a series of disruption and state which ones have been a significant source of disruption to their supply chain during the past twelve months. Unplanned IT and telecommunication outage emerged in the top two from 2009-2018, with seven consecutive years from 2012-2018 as the number one. Cyber-attacks and data breach also emerged in the top three from 2015 (BCI, 2009-2018). Unplanned IT/Telecom and cyber-attack was also featured prominently as concerns when participants were asked to predict future risk to their supply chains the next five years (BCI, 2009-2018).

Table 3: Top 3 sources of supply chain disruption past 12 months. Derived from" BCI Supply chain resilience reports 2009-2018". By Business Continuity Institute (2009-2018).

Rank	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1st	IT or telecom disruption	Adverse weather	Adverse weather	Unplanned outage of IT/telecom	Unplanned outage of IT/telecom	Unplanned IT or telecom outage	Unplanned IT or telecom outage	Unplanned IT or telecom outage	Unplanned IT or telecom outage	Unplanned IT or telecom outage
2nd	Adverse weather	IT or telecom disruption	Unplanned outage of IT/telecom	Adverse weather	Adverse weather	Adverse weather	Cyber attach and data breach	Loss of talent/skill	Cyber attach and data breach	Adverse weather
3rd	"Swine flu" AH1N1	Outsourcer service failure	Transport Network disruption	Outsourcer service failure	Outsource r service failure	Outsourcer service failure	Adverse weather	Cyber attach and data breach	Loss of talent/Skill	Cyber-attack and data breach

Instances of supply chain disruptions associated with ICT are well documented. TSMC one of the largest computer chip contract manufacturers experienced delays to shipments due to factories affected by a computer virus (White, 2018). Another example is the Chinese car manufacturer Manganese Bronze which in an effort to reduce the complexity of their global

supply chain transitioned to a new IT system, that caused confusion and a "combination of system and procedural errors" slowing the production to a halt (Jacobs and Reed, 2012).

Perhaps the best example in recent times is the cyber-attack experienced by Norsk Hydro, a global actor in aluminium production. In the spring of 2019, Norsk Hydro experienced a gruelling cyber-attack in the form of ransomware that halted production at several plants as the company scrambled to identify the virus and restore their IT systems (Milne, Sanderson and Coulter, 2019). The case of Norsk Hydro is but one example in the increasingly lucrative field of cybercrime which is estimated to create $1.5 trillion in profits for 2018 (McGuire, 2018).

These insights from academics and organizations suggest that the rapid proliferation and increased reliance on ICT systems in conjunction with the managerial challenges faced when dealing with such systems have led to an increase in supply chain disruptions related to ICT. Louis and Pagell (2019) surmise the risk posed by the cyber domain under the category they labelled *infrastructure*. This category encompasses risk factors associated with ICT infrastructure such as hacking, denial of service and incompatible IT system as well as risk factors associated with a firm's broader infrastructure such as equipment failure (Louis and Pagell, 2019). Based on this the following hypothesis is formulated:

H_4: *Infrastructure risks have increased as a source of supply chain disruptions during the last decade.*

2.3 Summary

In this chapter, academic literature and influential reports from organizations concerned with risk management have been reviewed to gain insight into different sentiments surrounding the sources of supply chain disruptions. The literature and reports reviewed naturally represent a finite set of perspectives and as such might not fully grasp all perceptions surrounding supply chain disruptions. Nevertheless, the presented perspectives represent the views put forward by a diverse selection of established actors within the SCRM community. Consequently, the authors believe the presented perspectives will provide a representable presentation of significant issues put forward by the scholarly literature and the risk management communities.

The first perspective that was addressed was the increase in disruption from external risk factors caused by a progressively complex and uncertain world in combination with the global nature of modern supply chains. Modern supply chains have become complex webs of interconnected firm across vast geographical distances leaving them susceptible to disruption from a new range of external risks. Particularly, the WEF has focused on the increased threat external factors pose to supply chains ranging from natural disasters to the challenges introduced by the political interplay between states.

The next topic of inquiry was the increased attention given to *catastrophic* risks in the wake of events such as the 9/11 terrorist attack and the great Japanese earthquake in 2001. Both academics and the risk management communities argue that the increased vulnerability of supply chains, in part due to cost reduction and increased efficiency, has left supply chains more susceptible to catastrophic events. This notion of *catastrophic* risks posing a significant threat to supply chains and the global economy as a whole is notably professed by the WEF. Extreme weather, natural disasters and conflicts have been featured prominently in several of their reports. A potential explanatory factor behind this can be the frequent occurrences of natural- and man-made catastrophises, which have seen a substantial increase over the last half-century.

Next, the sentiment that risks *external to the supply chain* has been given an unwarranted level of attention was explored. Despite the attention given to external risk factors, some academics suggest that risks *internal to the supply chain* still pose a significant threat to supply chains. Researchers also argue that the increasingly competitive nature of the global economy has led firms to focus on efficiency in their supply chains. In the drive for efficiency, firms have become dependent on an uninterrupted flow of materials, resulting in an increased vulnerability to disruptions *internal to the supply chain* including difficulties with predicting demand and suppliers that are unable to deliver. This line of reasoning finds support in several surveys where traditional supply and demands side risks were considered the most pressing sources of supply chain disruptions.

Lastly, the notion of *infrastructure* risks and the increase in disruptions associated with ICT systems were addressed. The main rationale behind this notion is that as supply chains have become increasingly dependent on these systems, they have also become increasingly exposed to supply chain disruptions associated with these risks. This is a topic of concern for both

academics and practitioners with reports indicating that firms consider themselves unprepared for this threat. Particularly notable is the attention given to this by the BCI were the respondents have considered unplanned outage of IT/telecom as one of the main sources of supply chain disruptions across the last decade. In addition to unplanned IT outages, cyber-crime has increasingly gained attention as a threat to supply chains as recently witnessed with the cyber-attack on Norsk Hydro which forced a prolonged production halt.

The literature review resulted in the formulation of the following hypotheses.

- **H_1:** Risks external to the supply chain have increased as a source of supply chain disruptions during the last decade.
- **H_2**: Catastrophic risks have been the most predominant source of supply chain disruptions during the last decade.
- **H_3**: Risks internal to the supply chain have been the most common source of supply chain disruptions during the last decade.
- **H_4:** Infrastructure risks have increased as a source of supply chain disruptions during the last decade.

By testing the above hypotheses for support the authors hope to offer insight which can help answer the research question of this study:

What have been the main sources of supply chain disruptions over the last decade, and do observed patterns correspond with expectations put forward in the scholarly literature and the risk management communities?

The examination of the hypotheses shed light on the research question in two ways. First, it quantifies what risks have been the main sources of supply chain disruptions over the last decade Second, the results from this examination also offer insight into the accuracy of the scholarly literature and reports from the risk management communities. Each hypothesis captures a common perspective on the sources of supply chain disruptions and by supporting or refuting the hypothesis, insight into the accuracy of scholarly literature and reports from risk management communities can be attained.

In addition to serving as the foundation for the development of the hypotheses, the literature review provides insight on a key consideration that served as the motivation for this study; The importance of triangulating sources when assessing supply chain risks. Different sources from academia and influential organizations provide compelling arguments and evidence for different views regarding sources of supply chain disruptions. Depending on the source of knowledge different conclusions as to what have been the most prominent sources of supply chain disruption can be ascertained. While some organization, academics and practitioners focus to a large extent on risk factors *external to the supply chain*, others put forward the argument that despite the focus given to external risk factors and in particular *catastrophic* risks, risks *internal to the supply chain* are still a pressing concern for businesses. This serves to illustrates the challenges facing managers when trying to assess risks to their supply chains. Furthermore, it stresses the need to implement measures to monitor and record on supply chain disruptions.

3 Research Methodology

In this chapter the research methodology of this study is presented. Research methodology describes how the researcher has set about to systematically solve the research problem including the methods chosen and the rationale behind them (Kothari, 2004). The chapter is structured in the following manner: First, the selection of methodology is presented. Then, the overarching research design is shown before going through the specific steps taken to collect, code and analyse the data. Finally, the reliability and validity of the study are addressed.

3.1 Selection of methodology

The purpose of this research was two-folded. The first aim was to provide an answer to what have been the sources of supply chain disruptions over the last decade. The second aim was to investigate how the results from this inquiry aligned with commonly held views on sources of supply chain disruptions put forward in academia and risk management communities. Deciding on the appropriate methodology to achieve these two aims several aspects had to be taken into consideration.

First, the literature review uncovered a research gap in the form of limited empirical research (Sodhi et al., 2012). In particular statistically driven empirical research has seen few attempts within the field (Sodhi et al., 2012; Ho et al., 2015). Ho et al. (2015) argue that empirical methods have attracted considerably less attention than qualitative methods such as literature reviews and concept developments. Furthermore, Ho et al. (2015) point out that empirical research has been used less than simulations, mathematical programming and other analytical methods which have gained considerable attention as SCRM has matured beyond merely defining concepts. One of the main reasons for the lack of empirical studies has been the challenges with gaining access to the industry (Ho et al., 2015). Challenges with gaining access to the industry have been attributed in part to a lack of common understanding and clear definitions which makes it difficult to communicate with the practitioners (Ho et al., 2015). Others have attributed the lack of empirical research to the challenges associated with the collection of data (Sodhi et al., 2012). This is not unwarranted knowing that a substantial number of firms lack regimes to report on supply chain disruptions (BCI, 2018).

Given the above-mentioned research gap, an empirical approach to the study was decided upon. The authors believe an empirical study will provide novel contributions to the field of research by responding to the call for empirical driven studies. It would also be suitable to fulfil the first aim of the study which is to provide an answer to what have been the sources of supply chain disruptions over the last decade. However, this decision brought with it the known challenge of acquiring data which was considered to be especially demanding for this study as the aim was to investigate patterns over a ten-year period. Because of this rather expansive scope of ten years, it was deemed unfeasible to acquire data through case studies or surveys, therefore an alternative approach was needed.

An alternative approach previously used within SCRM research have been the collection of second-hand data through readily available media sources. Hendricks and Singhal (2003) utilised this method to acquire data on supply chain glitches from the text archives of the Wall Street Journal and the Dow Jones News Service covering the period from 1989 until 2000. The result was a sample of 519 glitches. Extrapolating from textual sources in this manner is referred to as content analysis (Weber, 1990). Applying this approach to the study would circumvent the challenges of gaining access to suitable data and allow for data collection across ten-years from an available source that has previously yielded results. Based on these considerations content analysis was select as the primary research method for this study. Content analysis is regarded as a versatile method that can be conducted in a wide range of manners depending on the need of the particular study, and as such the approach selected for this study is described in detail in section 3.2 (Weber, 1990).

3.2 Content analysis

Content analysis refers to the process of systematically classifying segments of text for categorisation (Rose, Spink and Canhoto, 2014; Weber, 1990). The purpose is to reduce the often-unstructured textual material from sources such as newspaper articles into manageable pieces that can provide knowledge, new insights or a presentation of facts (Weber, 1990). Content analysis has been applied to a wide range of social science topics, such as describing trends in communication or researching cultural patterns in society. However, it has seen limited use in management research (Rose et al., 2014). In relation to studies on SCRM, this also seems to be the case. It is to the authors´ knowledge only Hendricks and Singhal that have adopted a

research design with similarities, in the form of event studies on the economic impact of supply chain disruptions (Hendricks and Singhal, 2003, 2005a, 2005b, 2014).

Content analysis can be approached from both a quantitative or qualitative perspective in an inductive or deductive manner (Elo and Kyngäs, 2008). Quantitative research in the context of content analysis refers to frequency counts of word, phrases or ideas from text (Easterby-Smith, Thorpe and Jackson, 2015). These counts can then be can be used as either criterion (dependent) or predictive (independent) variables on which a wide range of statistical techniques can be applied, including trend analysis and hypothesis testing (Insch, Moore and Murphy, 1997). In line with the need for more statistical driven empirical research, and to provide a compelling answer to the source of supply chain disruption across a ten-year timeframe it was decided to approach content analysis from a quantitative perspective. This approach allowed for the use of frequency counts of supply chain disruptions extrapolated from the text for subsequent analysis using statistical methods.

An inductive approach to content analysis is used if there is limited former knowledge about the phenomenon under scrutiny and involves creating new categories from the acquired data (Elo and Kyngäs, 2008). A deductive approach on the other hand is used when researchers seek to test previously established categorisations, concepts, models or hypotheses (Elo and Kyngäs, 2008). Deductive content analysis involves the development of a predefined categorisation matrix and coding of the data into the respective categories (Elo and Kyngäs, 2008). As the aim of the study was to assess established perceptions on sources of supply chain disruptions it was deemed appropriate to approach the research from a deductive perspective, using established concepts from literature. As expressed above a deductive approach that is suitable for quantitative content analysis is hypothesis testing. As the second aim of the study was to contrast the findings on supply chain disruptions against common sentiments expressed within academia and risk management communities, the development of a series of hypotheses based on these sentiments was considered suitable. Hypotheses development would allow the study to present key perspectives on supply chain disruptions that could be tested against the data acquired.

3.2.1 Strength and weaknesses of content analysis

Content analysis has several appealing aspects. It allows for the use of secondary data from a wide range of sources including company reports and newspapers (Harris, 2001). These written

materials exist over a long period of time and can provide reliable data for an extensive period (Weber, 1990). Compared to traditional qualitative methods such as interviews, content analysis is considered less obtrusive and therefore reduces the reactivity bias associated with these type of methods (Insch et al., 1997). These strengths hold true for this research as well. Content analysis allows for the use of second-hand sources of data that have seen limited use within SCRM research, which in turn can contribute with new insights regarding supply chain disruptions. Such data sources allow for the capture of data on supply chain disruptions spanning the last ten years on a global scale, from different firms across several industries. Empirical research within SCRM have often involved surveys or case studies which might have introduced reactivity biases. By utilising content analysis this study can contribute with findings where reactivity bias has had little influence on the results, and in turn provide new perceptions that can amend the knowledge gained from surveys and case studies.

Although there are several key benefits to content analysis it is not without its own set of weaknesses. Particularly the challenges associated with the sampling and coding of data. Content analysis involves qualitative interpretations of the content of the texts and is therefore susceptible to bias as well as errors (Rose et al., 2014). Bias and errors can be introduced by the researchers´ selection of text for use in the analysis, through the development of categories or through the coder´s knowledge of the research question and/or the hypotheses (Insch et al, 1997). This study is no exception. Although this study utilises a quantitative approach to content analysis using count data, the sampling of the data involves a qualitative coding process performed by humans. As mentioned earlier this involves a great degree of interpretation on the part of the coders and leaves the data susceptible to biases and errors. Although measures can be taken to reduce the impact of using human coders, it is impossible to eliminate the effect entirely.

3.3 Research design

Research design is considered the plan of the research and outlines the various steps taken from the initial ide to finished product (Thomas, 2017). In this study the research design has been informed by the decision to use quantitative content analysis. There exists no definite approach on how to conduct a study centred around content analysis, it all depends on the specific challenges faced by the investigators (Weber, 1990). However, several authors have established suggestions that can serve as a guide when developing a research design. The design chosen for

this research is therefore derived in parts from several researchers such as Harris (2001), Insch et al. (1997), Weber (1990) and Krippendorff (2004). Their suggestions for the research design have in turn been adapted and amended to fit the nature of this study.

Figure 7 presents a chronological flow chart of the research design applied in this study. First, the research question and the hypotheses were developed based on a literature review. Then the data source was selected before the sampling strategy and unit of analysis were decided upon. Next, the tools used for coding of the data was developed, including the categorisation- and coding schemes. It was decided that a pre-test of the data source and coding scheme was necessary to ensure that they yielded a useful result before initiating the final data collection. After the pre-test, the data was collected and coded according to the coding scheme. Subsequently, the reliability and validity were assessed. Finally, the methods to analyse the data was selected and the data analysed. The actions carried out by the authors at each step is addressed in detail in the next sections.

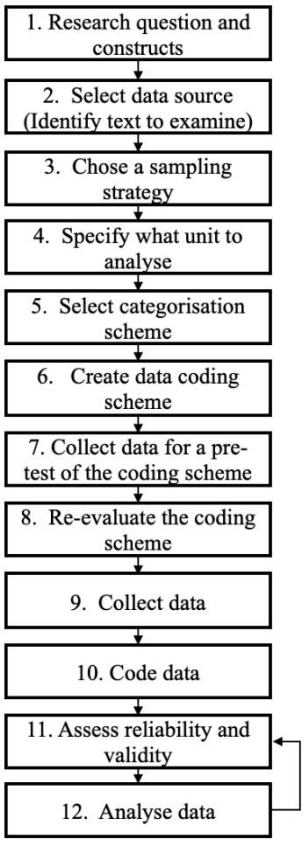

Figure 7: Research Design for this study. Layout derived from Insch et al. (1997) Content analysis in leadership research: Examples, procedures, and suggestions for future use.

3.4 Research question and constructs

In this section the development of the research question and hypotheses is discussed as well as the measures taken to validate the literature used.

3.4.1 Research question

The process of identifying the research question started with a hunch that there existed a discrepancy between what risks have been the focus of academia and risk management communities and which risks actually have been the source of disruptions to supply chains. To get an overview of existing literature on the sources of supply chain disruptions a literature review was conducted using the search engine Google Scholar together with Microsoft Academic. Search terms such as "supply chain risks", "supply chain risk categorisation" and "sources of supply chain disruptions" were used. Several quality articles mentioned different risk sources, but empirical evidence stating which of these sources that had been the most predominant source of supply chain disruptions were scarce. Also, reports from renowned risk management communities such as the WEF and the BCI were reviewed. These reports gave some insight into which risks had been considered important during the last decade, but with the limitation that the data was based on surveys and not first- or second-hand data. This sparked an interest to compare what literature and risk management communities had focused on as sources behind supply chain disruptions against empirical data on what actually had been the sources of supply chain disruptions. The lack of empirical data and the believed discrepancy between the focus of literature and risk management communities led to the research question which tries to answer how the expectations put forward in the scholarly literature and risk management communities compare against disruptions that have occurred during the last decade.

3.4.2 Hypotheses

After establishing the research question the next step was to formulate a set of hypotheses that could contribute to answering the research question. Drawing inspiration from Wagner and Bode (2006, 2008) it was decided to develop the hypotheses around central topics that had emerged in academic literature and reports from risk management communities. The intent was to capture different perspectives on the sources of supply chain disruptions. The end result was four hypotheses each centred around a different topic regarding the sources of supply chain disruptions that have garnered notable attention from academics and practitioners. This approach

to hypotheses development was considered suitable for this study as it allows the exploration of several sometimes contrary perspectives on the nature of supply chain disruptions. If the hypotheses were to be limited to a single report or academic work, they would not be able to fully capture the different perspectives on the sources of supply chain disruptions.

3.4.3 Literature review and validation

When conducting the literature review for this study articles were first assessed based on their number of citations to limit the scope to articles from well-renowned authors. It became apparent early on that there was limited consensus within the field of research with regards to definitions of key concepts. Consequently, the authors saw a need to look at more recent and less cited articles and trace the references used by these backwards to look how the concepts have developed. By starting with the latest articles, the authors were able to get an overview of how the concepts had evolved over time and which authors who were considered most influential. The work of Louis and Pagell (2019) and Ho et al. (2015) proved to be especially useful to trace such developments.

After the theory chapter and hypotheses had been completed the journals of the articles used were checked against the Academic Journal Guide 2018 (Chartered Association of Business Schools, 2018). A few articles came from journals not included in the list. The use of these in the study was checked. If used as an independent source for a concept in the literature the reference was removed altogether. If used as a supplementary source to another reference from a well-renowned journal the reference was kept. Some of the references came from academic books. The earlier work of the authors of these books was checked. If the earlier work were published in quality journals from the Academic Journal Guide (2018), the reference was kept.

The reports from risks management communities used was assessed based on their method for data collection and scope. If the method for data collection was described in too little detail, the report was abandoned. Reports that have been issued several times or annually were also prioritised.

3.5 Data collection and coding

In this section the steps taken to collect and code the data is addressed. First, the selection of the data source is presented, including the advantages and disadvantages associated with the chosen source. Next, the sampling strategy and which data units to collect are addressed. Then the categorisation- and coding schemes are described including the coding manual and coding form. Lastly, the pre-test and final data collection are discussed.

3.5.1 Data source

After establishing the research question and hypotheses, the next step in the research process was to select the data source i.e. the texts that should be examined. Insch et.al. (1997) points out several considerations that researchers should be mindful of when selecting a data source. These considerations include assessing the validity of the text source and whether to analyse whole sets of texts or use a sampling method to select fewer items of text.

For this study it was decided to utilise the Financial Time (FT) online archive as the data source. The FT archive has several advantages as a data source. FT is a well-known and regarded institution in financial journalism that provides a comprehensive online archive with a wide selection of articles. These articles cover several decades from different branches of business across the globe. The Wall Street Journal was also considered but could only provide an archive that spanned the last four years and was therefore dismissed. Consequently, the authors decided that using the FT archive would provide the best opportunity to collect a suitable selection of articles needed for the study.

Although the FT archive has advantages as a data source it also has several disadvantages. FT relies on funding through reader subscription. To attract subscribers the FT must produce news on events that are considered interesting to the readership. This might skew the data towards high impact disruptions that have occurred at large companies such as Samsung, Apple and Toyota. In addition to adhering to major headline-grabbing events, the articles are often based on information from annual reports and statements from the companies themselves. It is in the interest of these firms to control the narrative and divulge the disruptions they deem necessary to the public. The result of this might be that disruptions caused by events the companies consider outside of their control will feature prominently in their statements. Additionally, more complex

sources of disruption where it is harder to discern a logical cause and effect might also end up being omitted from the dataset. A breakdown at a factory as a source of supply chain disruption might be considered easier to report on as opposed more intricated sources such as strategy, decision making and cultural differences. In order to try and reduce the bias towards high impact disruptions, it was necessary to take this into account when developing the sampling strategy. This is addressed in the next section.

3.5.2 Sampling strategy

After selecting the data source, a suitable sampling strategy needed to be decided on. It became apparent early on that random sampling of articles from the archive would be too time-consuming and therefore regarded as unfeasible. The FT provides millions of articles from a wide range of topics and it was necessary to find a sampling strategy that could narrow this selection down. It was therefore decided to use what Krippendorff (2004) refers to as relevance sampling as a mean to lower the number of articles that needed to be reviewed. Relevance sampling involves using the search engine to gradually layer keyword into search strings such as *«Supply chain" AND (Glitch OR Glitches OR Disruption OR Disruptions OR Loss OR Losses)*. This sampling approach is in line with the strategy applied by Henricks and Singhal in their study on supply chain glitches (Hendricks and Singhal, 2003, 2005a, 2005b, 2014). Professor Singhal kindly provided the authors with a selection of the search strings utilized by him and Professor Henricks in their research. These search strings together with an additional search string developed by the authors were used to search the FT web archive. All the search strings and the corresponding number of articles found per search can be found in appendix B.

This sampling strategy allowed the authors to acquire a relevant set of articles. However, it also imposed certain limitations on the utility of the dataset. Relevance sampling does not yield a dataset that is probabilistic and therefore cannot be used to infer about the total population of texts in the FT archive (Krippendorff, 2004). As the intent behind the study was to collect data for categorisation and comparison, and not for the purpose of predicting the probability of occurrences this limitation was viewed as acceptable.

As a measure to try and reduce the bias towards high impact disruptions it was decided to use search words that were not directly derived from the classification scheme of Louis and Pagell (2019). Instead, it was decided to use more general search words such as delay, shortage, and

unavailability rather than catastrophic, terrorism, demand or other category specific words. This might have helped to reduce the bias towards high profile external disruptions, but in turn, also created search strings more inclined towards risks *internal to the supply chain* and *internal to the firm.* Considering the likelihood that the FT archive was going to be biased towards high impact disruptions this was considered an acceptable trade-off.

3.5.3 Unit of analysis

After selecting the FT archive as the data source, the next step was to select the unit of analysis which is the basic unit of text that is to be classified (Insch et al., 1997). The choice was between five possible units that have been commonly used in content analysis: a) words, b) sentences, c) paragraphs or d) assigning the whole text to a category (Insch et al., 1997). Harris (2001) argues that it is important to select a unit of analysis that is suitable to the research question. In the case of this study, it was opted for analysing and classifying whole articles due to the research question which implies the use of a quantitative approach. Choosing the whole article as the unit of analysis allowed the authors to use each article as a count of a supply chain disruption which later could be used for statistical analysis.

Another important consideration when choosing the unit of analysis is that it suits the nature of the communication being analysed (Insch et al., 1997). Usually, analysing whole articles is challenging, especially when dealing with scholarly literature. In the case of this study the limited scope of the text in news articles from the FT, typically 1-2 pages, was considered feasible to read through and analyse (Weber, 1990). It was also deemed necessary to analyse whole articles in order to assess if a supply chain disruption had taken place and establishing the source of said disruption. To capture both the presence of a disruption and link it to a specific source would be challenging using word- or sentence counts.

3.5.4 Data categorisation scheme

After deciding on the unit of analysis the next step was to specify the different categories to assign the articles from the FT into. The development of a categorisation scheme involves several considerations that need to be addressed. The first consideration is between single versus multiple categories (Insch et al., 1997). In instances where a unit of analysis fits into several categories researchers can choose between two approaches to categorisation. The first is to

assign the unit to only one category making a judgment of what category is most suitable. The second possibility is to assign the unit to multiple categories. For this study the first approach was chosen, assigning ambiguous articles to the most fitting category. The rationale behind this choice was that a multiple classification scheme could create categories that are not independent of each other making further statistical analysis harder (Insch et al., 1997). A disadvantage of this approach materialises in instances of multiple disruptions from different sources contained within a single article. Under such circumstances opting for a single classification approach reduces the reliability of the data, as it increases the likelihood that coders might place the article in different categories. Weber (1990) therefore suggest that one should remove ambiguous units of analysis altogether. It was assessed that articles seldom clustered disruptions from different sources in the same article. Instances of clustering were found but not to an extent that removing these articles from the dataset would limit the findings. It was therefore decided to follow the recommendations put forward by Weber (1990) and remove ambiguous articles.

The second consideration was whether to use an assumed or inferred category scheme (Insch et al., 1997). In an assumed category scheme, the categories are defined prior to the data collection. Selecting an assumed category scheme is considered a deductive approach where the researcher seeks to acquire data in relation to already developed theoretical concepts (Insch et al., 1997). Opting for an assumed category scheme has the advantage of allowing for an easier comparison against existing literature (Insch et al., 1997). The disadvantage is that it imposes the ideas of the researcher or the category developer on the textual analysis. In an inferred category scheme, the categories instead emerge from the text source (Insch et al., 1997). This is considered an inductive process whose purpose is to develop theoretical constructs from the acquired data (Insch et al., 1997). The main disadvantage of an inferred category scheme is that it creates a multitude of new categories which makes it difficult to compare across studies (Insch et al., 1997).

For this study an assumed scheme was selected. The choice was primarily informed by the intent of the study which was to examine already established ideas regarding supply chain disruptions. Also, the recognised need within the field of research to test existing supply chain risk typologies to move towards a taxonomy served as justification for choosing an assumed categorisation scheme (Louis and Pagell, 2019). The categorisation scheme that was selected (table 4) is based on the work of Louis and Pagell (2019). For further details see section 2.1.4.1 and appendix A.

Table 4: Supply chain risk categorisation scheme derived from Louis and Pagell (2019).

Risk external to the supply chain	**Risks internal to the supply chain**	**Risks internal to the firm**
Competitiveness	Supplier operational	Infrastructure
Input market	Supplier economic	Strategic
Political risk	Cultural	Problem-specific
Catastrophic	Relational	Decision-maker specific
Financial market	Demand	Reputation
	Transportation	Capacity
	Inventory	Financial capacity (receivables)
	Legal, bureaucratic and regulatory	
	Sustainability	
	Financial capacity (Receivables)	
	Consumer risk	

3.5.5 Data coding scheme

Having decided on a categorisation scheme, the next step was to develop a coding scheme in order to classify the articles into the appropriate categories (Rose et al., 2014). When developing a coding scheme, the first decision that needs to be made is whether the coding should be carried out by humans or computers. Using computer programs utilising natural language processing designed to iterate through text was considered. However, due to the challenges of integrating these programs with the FT archive, it was decided that it would be more efficient to conduct the coding manually. After deciding to carry out the coding manually the next step was to develop a coding manual. A coding manual specifies how to carry out the coding to ensure that the coding is conducted in a systematic- and replicable manner (Rose et al., 2014). Figure 8 shows an excerpt of the coding manual used in this study.

Category: Denote a potential category the article can be assigned to base on the classification scheme developed. The list below is exhaustive and represent the possible categories that the coder can select from. An article can only be coded to one category. Detailed description of the various categories is available in the coding form.

Coding Keywords: List the keywords used to assign the article to a category.

Category Designation: The articles are assigning to a category using a predefined enumeration listed in the coding form.

Article	Category	Keywords	Designation
1	Catastrophic	Storm, flood, earthquake	Assigned to category = 4
2	Political Risk	Supply chain, delays Brexit,	Assigned to category = 3

Figure 8: Excerpt from the coding manual.

Next, a coding form based on the previously established categorisation scheme (Table 4) was developed. The coding form was created using Microsoft Excel and contained article number, serial number, article name, an abstract from the article text, keywords that triggered the coder to choose a specific category and the number of the category. An excerpt of the coding form is shown in figure 9. Initially a true or false approach to the categorisation was utilised where 1 = true and denoted the article as part of a category and NIL = false and not part of a category. However, the pre-test revealed that this approach was inefficient, and it was instead decided to enumerate the categories from 1-23.

Coder:					Category
A					
Article Serial Number	Article filename	Year	Content	Coding Variabes	Enumeration
1	Bang Olufsen Sound and fury	2018	A new logistics partner has caused delays in fulfilling customer orders, hurting sales in Emea and the Americas — respectively, 47 and 7 per cent of revenues.	Delayed customer orders	6

Figure 9: Excerpt from the coding form.

3.5.6 Pre-test and re-evaluation of the coding scheme.

Researchers emphasise the importance of conducting a limited pre-test using a small sample to evaluate the clarity and comprehensiveness of the coding scheme and the coding manual (Harris, 2001; Insch et al., 1997). Following these suggestions, it was decided to conduct a small-scale test using 50 articles coded individually by the authors. The pre-test uncovered several challenges. The coding manual was ambiguous in terms of whether an article could be placed in several categories or just one. This ambiguousness led to a discrepancy in output between the coders. It was therefore decided to state in the coding manual that one article could only be coded into a single category. Additionally, it was not stated clearly if several disruptions from the same article could be accumulated into one category, i.e. accruing 2 or more instances of supply chain disruptions belonging to the same category from a single article. To ensure consistency it was decided to state in the coding manual that an article could only be the source of one count of a supply chain disruption.

After resolving these issues, the coding manual and the coding form was updated and the test samples re-coded. Krippendorff`s Alpha was then calculated for the 50 articles to assess the reliability by testing inter-coder agreement (more on Krippendorff's Alpha in section 3.7.1). The result of the test is displayed in table 5.

Table 5: Calculation of Krippendorff´s Alpha using the SPSS kalpha macro.

	Alpha	Probability(p) of not achieving an alpha of at least			
Pre-test 50 samples	0.842	(0.60) p=0.001	(0.70) p=0.007	(0.80) p=0.259	(0.90) p=0.848

The calculation yielded an alpha of *0.842*. There exists no definite answer to what is considered an acceptable alpha as it depends on the complexity of the data being coded (De Swert, 2012). Some argue that an alpha as low as *0.60* is acceptable for complex data (De Swert, 2012). However, as a rule of thumb an alpha greater than *0.80* is considered to be adequate for most studies (Krippendorff, 2004). The calculated alpha of *0.842* is above the recommendation put forward by Krippendorff (2004) and was therefore considered acceptable.

The probability of not achieving a given alpha if the coding were to be conducted on units beyond the test sample of 50 is calculated using a bootstrapping algorithm (Hayes and Krippendorff, 2007). The calculation yielded a p-value of *0.007* and *0.259* for not achieving an

alpha of *0.70* and *0.80* respectively. In light of the data coded being relatively complex, with 23 different categories, the probability of *0.259* of not achieving an alpha of *0.80* when later coding the whole dataset was considered acceptable. Thus, the pre-test was considered successful and the data collection phase could commence without further changes to the coding manual.

3.5.7 Final data collection and coding

After addressing the concerns that emerged from the pre-test and amending the coding manual and form accordingly the next step was to retrieve the data. The data collection was carried out using the predefined search strings limited to the timeframe between 2009-2018. All searches were entered into a search log detailing the year searched, the number of articles retrieved, and the search string used (for more details se appendix B). The pre-established search strings resulted in a selection of 11 504 articles which in turn was manually vetted for relevance. The articles that were deemed suitable were given a serial number and named after the headline and stored in a folder. The data collection period lasted from 05.02.19 until 11.03.19 and resulted in 445 articles considered for coding into the categorisation scheme.

Initially the authors searched the same year using different search strings which resulted in several articles describing the same supply chain disruption. In order to reduce the likelihood of duplications, it was decided to apply the full set of pre-defined search strings on separate years. This reduced the number of duplicates and only a few duplicates were discovered during the final check before the coding phase. After the data collection phase was completed the 445 articles retrieved were imported into the coding form and coded into the categorisation matrix individually by the authors.

3.6 Data analysis

After the acquired data was coded the next step was to analyse it in order to assess support for the four hypotheses. The hypotheses required two methods of analysis. One which could discern if a main- or sub-category had been more prominent then the others, and one which could detect the presence of any trend in the number of supply chain disruptions allocated to a given main- or sub-category over the decade.

3.6.1 Analysis of significant differences between categories

In order to test the hypotheses claiming a sub- or main-category has been more predominant than the others, a test for statistically significant differences between categories had to be conducted. Which test to be used depends on the type of data to be analysed. In the case of this study, the data to be analysed is the number of disruptions per category per year. Such data is often referred to as counts, which take the form of non-negative integers. Using ordinary linear regression to counts is inappropriate due to counts being limited to discrete values which are bound at zero. By using linear regression on counts, one will leave the possibility open for the regression model to produce negative predicted values, which for counts is theoretically impossible (Cameron and Trivedi, 2013).

To model count data the Poisson regression model or one of its variants is often used as they are restricted of the predicted values to be non-negative integers (Gardner, Mulvey and Shaw, 1995). The purpose of these models is to decide which predictor variables that have a statistically significant effect on the response variable. (Cameron and Trivedi, 2013). In the case of this study category is the independent (predictor) variable, and the number of disruptions is the dependent (response variable). Also, year was added as a control variable in the model. If a statistically significant effect of category on the number of disruptions allocated can be confirmed, the parameters estimates of the regression model can be compared between the different categories to see which one has had the larger effect on the number of disruptions. Furthermore, to assess if the differences in the effect on the number of disruptions between the categories represent real differences or are likely to be due to chance variation, a pairwise comparison of the estimated marginal means should be done. The comparison is based on the predicted means of the regression model. Each category is pairwise compared against all the other categories in in the model. If a significant result can be confirmed in one of the comparisons, the difference in estimated means can be assessed to discern if the category has had a larger or lesser effect on the number of supply chain disruptions than the category it is compared against. The conclusions of the comparison can then be used to find support, partial support or no support for the hypotheses.

In this study there are two different datasets to be analysed for significant differences. The first use the three main-categories as the independent variable, and the number of disruptions per main-category per year from 2009-2018 as the dependent. The second use the 23 sub-categories

as the independent variable and number of disruptions per sub-category per year from 2009-2018 as the dependent.

3.6.1.1 Choice of regression model

The Poisson regression contains a strong assumption that the mean of the response variable is equal or lower than the variance (Cameron and Trivedi, 2013). An examination of the data indicates the data exhibit overdispersion. Descriptive statistics of the data confirms this. The main-categories yielded a mean of *14,833* and variance of *59,592.* For the sub-categories, the mean was *1,956* and the variance *7,413*. With the presence of overdispersion, the maximum likelihood t-values may be considerably overinflated when using Poisson regression. Consequently, the authors follow prior studies (Bellamy, Ghosh and Hora, 2014; Bode and Wagner, 2015) when opting for negative binomial regression. This model adds an extra parameter to compensate for the overdispersion (Cameron and Trivedi, 2013). Another consideration to be taken into account with count data is the presence of excessive zeroes. For the three main-categories, this was not an issue due to the absence of zeroes. However, with the sub-categories several categories had no disruptions allocated to them for certain years. To model such data the hurdle and zero-inflated regression models are often believed to fit the data better (Zeileis, Kleiber and Jackman, 2008). Thus, for the sub-categories the negative binomial-, hurdle-, and zero-inflated model were applied to the data in the statistical package R to test which model that modelled the data best based on the Akaike's Information Criteria (AIC). The result of the test is displayed in table 6, a lower AIC value indicates a better model fit.

Table 6: Comparison of AIC values for negative binomial-, hurdle-, and zero-inflated regression model.

	Negative Binomial	Hurdle	Zero-Inflated
AIC	690	760	712

Based on the AIC values and the above discussion, a negative binomial regression was chosen to analyse the data for both the main- and the sub-categories.

3.6.1.2 Goodness of fit

In order to evaluate the overall performance of the regression model the goodness of fit had to be evaluated (Cameron and Trivedi, 2013). Table 7 summarizes the goodness of fit values associated with the negative binomial regression model of both datasets. Four different measures of goodness of fit are displayed.

Table 7: Goodness of fit measures for negative binomial regression.

	Deviance/Df	Pearson Chi-Square	Omnibus test	Test of model effects
Main-categories	1.010	0.999	0.000	0.000
Sub-categories	1.000	0.909	0.000	0.000

- **Deviance/DF** is a measure of how well the extra parameter in the negative binomial regression model compensates for the overdispersion of the data. A value closer to 1 is considered good, indicating that the model is able to compensate for the overdispersion in a good manner.
- **A Pearson Chi-Square** value of above *0.05* indicates that the model fits the data well.
- **An omnibus test** is a test of the overall performance of the model. A value of less than *0.05* indicates that the model is a significant improvement compared to the null model with no predictor variables.
- **Test of model effects** is a measure of how well the independent variable can predict the dependent. In this case category as a predictor for the number of counts. A value of less than *0.05* is statistically significant indicating that the dependent variable has explanatory power on the independent variable.

Looking at the values in table 7, negative binomial regression clearly fit the data for both datasets, and an analysis can be conducted.

3.6.2 Analysis of trends

To test hypotheses claiming that there has been a positive or negative trend within any given category during the last decade a trend test must be applied to the data. In order to conduct such analysis, the data has to be a time series with observations occurring at fixed time intervals. In the case of this study number of disruptions per main- and sub-category per year from 2009-2018 act as the time series to be analysed.

3.6.2.1 Choice of trend model

Due to the data being non-parametric, the choice between a Mann-Kendall (MK) or the Spearman's rho (SR) trend test had to made (Yue, Pilon and Cavadias, 2002). Both the MK and SR tests are used to detect trends in time series and have commonly been used to assess trends in

hydro-metrological time series such as temperature (Yue et al., 2002). Several studies have compared the power of the MK and SR test against each other but have found very little basis for choosing one over the other (Daniel, 1978; Yue et al., 2002). Consequently, the authors opted for the MK test due to it being more widely used in research (Yue et al., 2002). The result of the MK test is a p-value which indicates if a significant trend is detected, and the Mann-Kendall statistics (S) which implies a positive trend when positive, and a negative trend when negative.

In order to use the MK test the data has to conform to certain assumptions. First, it should not exhibit signs of autocorrelation (Kendall, 1975). Hamed (2006) points out that autocorrelation in relation to the MK test often is caused by seasonal effects. The data of this study is not likely to be affected by seasonal effects, due to the sampling interval being yearly. However, certain events occurring late in one year, e.g. a tsunami, might have affected the number of supply chain disruptions allocated to risks *external to the supply chain* the following year. With the presence of autocorrelation comes an increased likelihood of detecting a "false" trend using the MK test. Thus, the data should be tested for autocorrelation before moving on with the analysis. In the case of autocorrelated data, variants of the MK trend test can be used (Yue and Wang, 2004). All the relevant time series for the main- and sub-categories were tested for autocorrelation using the autocorrelation function and partial autocorrelation function in SPSS (IBM, 2019). For the time series which showed signs of autocorrelation the modified version of the Mann-Kendall test developed by Hamed and Rao (1998) was used. The modified test corrects the variance to address the issue of autocorrelation. Both the MK trend test and the modified version of it was conducted with the statistical package R (Patakamuri,S.K, O'Brien and Patakamuri, M. S. K., 2019) An overview of which test used to the different categories can be found in appendix C.

Second, the sample size has to be sufficient. There seems to be no consensus on the required sample size to conduct the MK test, with suggestions spanning from 8 to more than 10 (Statistics how to, 2016; Kendall, 1975). However, more samples are believed to be better in order to reduce the probability of detecting a false trend. According to Kendall (1975) a samples size of 10 or more is sufficient to detect trends. In the case of this study all trends are analysed using 10 samples recorded yearly from 2009-2018, which conforms with the recommendations put forward by Kendall (1975). Based on the above discussion, the authors believe the MK test to be appropriate to examine the data for the presence of trends.

3.7 Reliability and Validity

To assess whether the results of the study could be reproduced with the same result by another researcher, and if the results actually explains the phenomenon under scrutiny the reliability and the validity of the study have to be addressed (Thomas, 2017). The next sections will first look at reliability in relation to the data collection and coding before addressing internal and external validity.

3.7.1 Reliability

Krippendorff (2004) suggests that there are three levels of reliability in the context of content analysis in ascending order: *stability*, *reproducibility* and *accuracy*. *Stability* is achieved when using only one coder that codes the same data numerous times and the result are compared to each other. However, this is considered the lowest form of reliability and the authors instead chose to strive for *reproducibility* by using two coders that coded the data independent of each other. Using several additional coders would have increased the reliability of the data, but due to time constraints this was not possible. Nevertheless, by utilising two coders the effect of bias, coding errors and a potential ambiguous coding scheme might have had on the final results were reduced. The highest form of reliability, *accuracy*, requires that the data is compared to a known norm or standard and is therefore seldom achieved in research using content analysis (Krippendorff, 2004). The same holds true for this study as there are no standard measures to compare the data against.

When utilising two coders an intercoder-agreement is a common measure of reliability (Lombardi, Snyder-Duch and Bracken, 2002). Intercoder-agreement is the extent to which independent coders are able to evaluate the characteristic of a text and reach the same conclusion (Lombardi et al., 2002). There have been utilised several coefficients to asses intercoder-agreement in content analysis such as Scott´s Pi, Cohen's Kappa and Krippendorff`s Alpha (Hayes and Krippendorff, 2007). For this research it was decided to utilise Krippendorff`s Alpha due to the calculations ability to account for two or more coders, different type of variables (nominal, ordinal, interval, ratio) as well as being applicable to data with missing values and small sample sizes (Krippendorff, 2004). Krippendorff`s alpha was calculated by importing the dataset into SPSS and applying a SPSS MACRO developed by Hayes and Krippendorff (2007). The calculation resulted in an alpha of *0.844* with a 95% confidence interval of *[0.807, 0.878]*

(Table 8). Krippendorff (2004) argues that there exists no common definition of what the minimum allowable alpha for any given dataset should be and argue that this depends on the purpose of the project. However, Krippendorff provides a guidance that an alpha of *0.80* or greater can be considered acceptable in most instances (Krippendorff, 2004). Based on this guidance an alpha of *0.844* was considered acceptable for this study.

Table 8: Result from calculating kalpha using the SPSS kalpha macro.

	Alpha	95% confidence interval lower limit	95% confidence interval upper limit
445 samples	0.844	0.807	0.878

3.7.2 Validity

Typically, two types of validity need to be addressed. Internal validity, if the results are attributable to the independent variable and not some other rival explanation, and external validity which gives an indication if the results from the research can be generalized across to other groups (Onwuegbuzie, 2000).

3.7.2.1 Internal Validity

Two different methods have been used to analyse the data. Negative binomial regression and a Mann-Kendall trend test. Negative binomial regression was applied to the number of disruptions as the dependent variable, and category as the independent. In order to assess the validity of the results, year as an alternative independent predictor variable was used to test whether year could explain the difference in the number of supply chain disruptions better than category. The test yielded no significant result neither for the main- or the sub-categories with a p-value of *0.698* and *0.872* on model effects respectively. For the Mann-Kendall trend test an alternative explanation for the trends could be a trend in the number of disruptions recorded per year rather than a trend in disruptions related to any given category. To test this a Mann-Kendall trend test was conducted on the total number of disruptions recorded yearly from 2009 to 2018. The test yielded no significant trends with a p-value of *0.279*. These two tests indicate that the internal validity is acceptable and that the chosen independent variables are those with the best explanatory power on the dependent.

With content analysis, the data generation relies on a qualitative assessment of the content of articles. This process is subject to different biases of the coder. Such biases e.g. bias towards

certain categories could be alternative explanations to some of the results. The problem with these biases is that it is almost impossible to quantify what effect they might have had on the dependent variable. However, by conforming to the guidelines of Krippendorff (2004) for content analysis, measures were taken to reduce these biases as described earlier in this chapter. Consequently, the authors asses the internal validity to be sufficient to use the results from the analysis to answer the research question.

3.7.2.2 External Validity

The main issue regarding external validity in this study is the data source. As previously outlined in the section on data collection, there are a number of limitations induced using the FT as a data source. First, the FT naturally will be biased towards major disruptions. Much of their content is based around quarterly- and annual reports of companies. Small supply chain disruptions which have not caused any major loss might not be included in such reports, making the data biased towards major disruptions. Second the FT mostly writes about large global firms such as Apple, Boing and Glencore. Even though there are some exceptions, most of the supply chain disruptions were related to large firms. Firms from all five continents are represented in the data, thus the conclusions drawn in this study are applicable for firms all over the world but might not be applicable to smaller firms with a shorter supply chain. Third, the FT only report on disruptions that have happened. Potential disruptions that were averted might amount to a considerable amount which manages should be aware of, but these are not included in annual reports issued by firms, and therefore not captured in the dataset of this study.

The limitations on the FT as a data sources limits the generality of the findings to large global firms. However, also managers of smaller firms should be interested in how the findings align with literature and risk communities in order to broaden their perspective on the sources of information for their risk assessment process.

3.8 Summary

Table 9 summaries the various steps in the research design and the actions taken at each step in this research project.

Table 9: Summary of the steps conducted in the research project. Layout adapted from Harris (2001).

Step	Actions
Identify Research question(s) and constructs.	Research question and four hypotheses developed through literature study.
Chose a sampling strategy.	Decided to use relevance sampling using predefined search strings.
Select data source (Identify text to examine).	Financial Times online archive from 2009-2018.
Specify what unit to analyse.	Articles.
Select a categorisation scheme.	Selected an assumed categorisation scheme developed by Louis and Pagell (2019).
Create a data coding scheme.	Developed a coding form and manual based on the categorisation scheme.
Collect data for a pre-test of the coding scheme.	Collected 50 articles. Coded by two coders.
Re-evaluate the coding scheme.	Changed the coding manual and the coding form. Assessed reliability.
Collection and coding of data.	Retrieved 11 504 articles Financial Times archive. 445 articles suitable for coding.
Assess reliability and validity.	Calculated kalpha to measure inter-coder agreement. Assessed internal and external validity.
Analyse data.	Analysis of 445 articles using SPSS and R to observe patterns and trends.

The next chapter will first outline the data characteristics of the 445 samples allocated to the 23 categories of supply chain risks. Then, the results of the analysis of the samples in the search of support for the four hypotheses will be presented.

4 Results

In this chapter the results from the statistical analysis to assess the hypotheses are presented. To analyse trends between 2009 and 2018 a Mann-Kendall trend test and the modified Mann-Kendall trend test were used. To analyse differences in the number of disruptions between the categories of supply chain risk a negative binomial regression model was applied.

The chapter is structured in the following manner. First, the characteristics of the acquired data are described. Then, the result from a trend test on the main-category risks *external to the supply chain* is presented in order to assess support for H_1. Next, differences between the sub-categories of supply chain risks are analysed to test support for H_2. Then the differences in number of disruptions between the three main-categories of supply chain risks are analysed to assess H_3. Finally, the result from a trend test on *infrastructure* risks is presented to test support for H_4.

4.1 Data characteristics

Searching the Financial Time archive from 2009 until 2018 using a set of predefined search strings yielded a selection of 11 504 articles. Relevant articles describing supply chain disruptions and their causes were then selected resulting in a dataset containing 445 accounts of disruptions. Figure 10 shows the percentwise distribution of supply chain disruptions from 2009 until 2018. 2009 and 2016 were the years with the least number of samples with 6,97% of the total sample size. The year with the highest number of samples was 2018 with 13,48%.

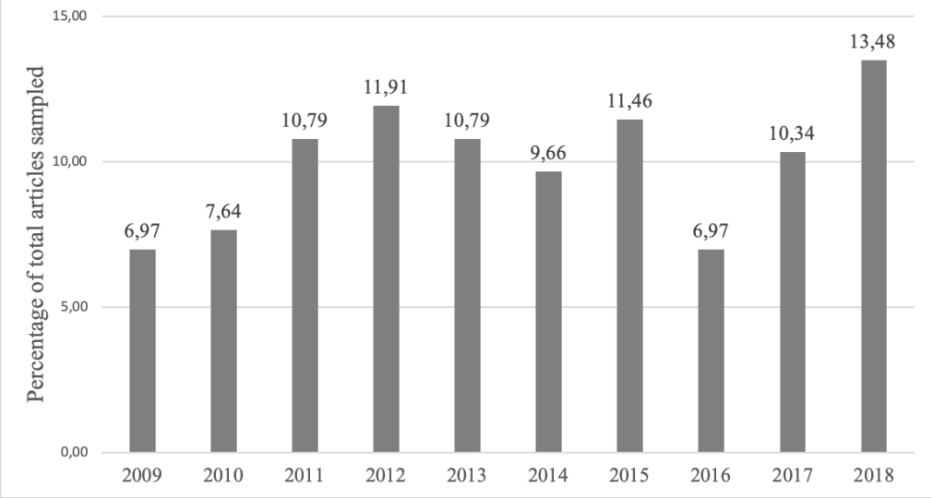

Figure 10: Yearly distribution of supply chain disruption announcements.

Coding of the 445 articles according to the predefined categorisation scheme resulted in the data distribution presented in table 10.

Table 10: Sample distribution across all categories of supply chain risk.

Main-categories	Number of articles alloacted
Risks internal to the supply chain	223
Risks external to the supply chain	143
Risks internal to the firm	79
Risks external to the supply chain	**Number of articles allocated**
Catastrophic	80
Political Risk	37
Financial market	12
Input market	9
Competiveness	5
Risks internal to the supply chain	**Number of articles allocated**
Supplier Operational	74
Legal, bureaucratic and regulatory	50
Demand	34
Transportation	31
Sustainability	9
Relational	6
Consumer risk	6
Inventory	5
Supplier Economic	5
Financial Capacity (Receivables)	3
Cultural	0
Risks internal to the firm	**Number of articles allocated**
Infrastructure	34
Reputation	16
Capacity	14
Financial Capacity (Recivables)	7
Decision-maker spesific	4
Strategic	4
Problem-spesific	0

Risks *internal to the supply chain* came out as the main-category with the highest number of supply chain disruptions allocated with 223 which amounted to 50% of all the disruptions. Risks *internal to the supply chain* were then followed by risks *external to the supply chain* with 143 (32%) and finally risks *internal to the firm* with the least amount of disruptions allocated with 79 (18%).

Between the different sub-categories saw *catastrophic* as the most prominent with 80 disruptions allocated, accounting for 18.0 % of all disruptions. *Catastrophic* was then followed by *supplier operational* with 74 (16.6 %). *Legal, bureaucratic and regulatory* with 50 (11.2 %). *Political* was allocated 37 (8.3%). *Infrastructure* and *demand* were each allocated 34 (7.6%). 31 of the disruptions were allocated to *transportation* (7.0%) *Reputation* received 16 (3.6%) disruptions. *Capacity* received 14 (3.1%) disruptions. *Financial market* 12 (2.7%) disruptions. *Sustainability* 9 (2.0 %.) disruptions and *input Market* 9 (2.0%) disruptions. *Financial capacity (Receivables*) 7 (1.6 %) disruptions. *Consumer risk* and *relational* were allocated 6 (1.3%) disruptions respectively. *Inventory*, s*upplier economic* and *competitiveness* each received 5 (1.1%) disruptions. *Decision-maker specific* and s*trategic* each tallied with 4 (0.9%) disruptions. *Financial capacity* was allocated 3 (0.7%). *Problem-specific* and *cultural* were allocated 0 disruptions.

4.2 Risks external to the supply chain

In order to assess whether there has been a developing trend in supply chain disruptions originating from risks *external to the supply chain* an analysis of the yearly number of disruptions allocated to the category was conducted. Observing how the number of disruptions has changed between 2009 and 2018 (Figure 11) it is hard to discern any clear trend. There has been an increase between 2009 and 2013, then a decline between 2013 and 2016 before a slight increase from 2016 to 2018.

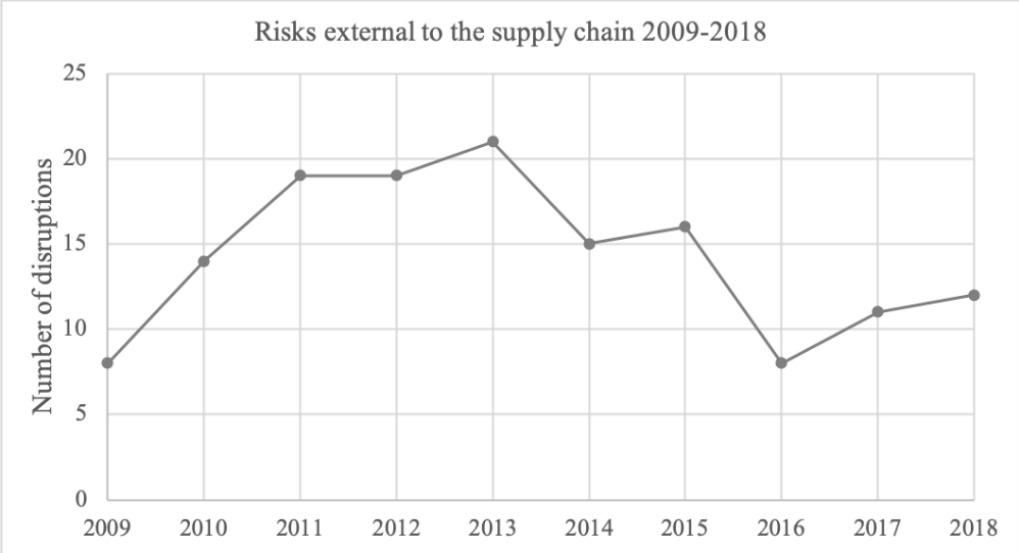

Figure 11: Yearly distribution of risks external to the supply chain.

A Mann-Kendall trend test (Table 11) applied to the yearly number of supply chain disruptions between 2009-2018 for the category *risks external to the supply chain* confirms the above observation

Table 11: Mann-Kendall trend test of risks external to the supply chain.

Main-Category	Sig.	S	Result
External to the supply chain	0.787	-4	No support for H_1

No statistically significant trend was detected with a p-value of *0.787*, thus refuting:

H_1: *Risks external to the supply chain have increased as a source of supply chain disruptions during the last decade.*

4.3 Catastrophic Risks

In order to test whether *catastrophic* risks have been the most prominent sources of supply chain disruptions, the 23 sub-categories of supply chain risks were compared (Figure 12). *Catastrophic* was the sub-category with the highest number of disruptions allocated with 80, accounting for 18.0 % of the total number of disruptions. *Catastrophic* was then followed by *supplier operational* with 74 (16.6 %), and *Legal, bureaucratic and regulatory* with 50 (11.2 %). These three categories stood out as the most common in terms of number of disruptions, with *catastrophic* as the most predominant, which lends support to H_2.

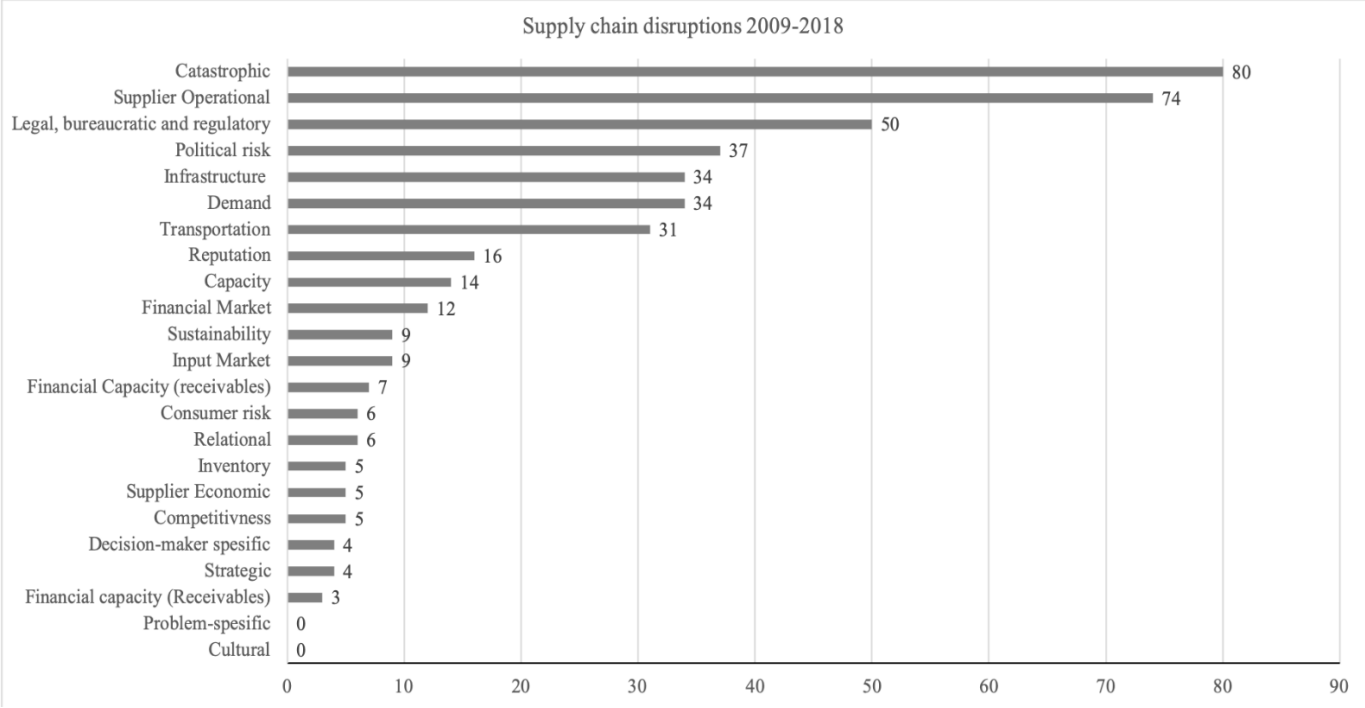

Figure 12: Number of supply chain disruptions across all categories.

To assess if the above observation could be considered statistically significant, a negative binomial regression model was applied to all the sub-categories. The number of disruptions in each sub-category per year served as the dependent variable and sub-category as the independent. Year was also added as a covariate. The analysis yielded the results displayed in table 12. *Political risk, catastrophic, supplier operational, demand, transportation, legal bureaucratic and regulatory, infrastructure* and *reputation* gave statistically significant results indicating that these have explanatory power on the number of disruptions allocated to the

various sub-categories. Year did not yield a statistically significant effect on the number of supply chain disruptions with a p-value of *0.144*

Table 12: Negative binomial regression across the sub-categories of supply chain risks.

Category	Sig.	Exp(B)	Result
Competitiveness	0.574	0.714	
Input market	0.629	1.286	
Political risk	0.000***	5.286	
Catastrophic	0.000***	11.429	Supports H_2
Financial market	0.273	1.714	
Supplier operational	0.000***	10.571	
Supplier economic	0.574	0.714	
Cultural	N/A	N/A	
Relational	0.787	0.857	
Demand	0.000***	4.857	
Transportation	0.001***	4.429	
Inventory	0.574	0.714	
Legal, bureaucratic and regulatory	0.000***	7.143	
Sustainability	0.629	1.286	
Financial capacity (Receivables)	0.227	0.429	
Consumer risk	0.787	0.857	
Infrastructure	0.000***	4.857	
Strategic	0.381	0.572	
Problem-specific	N/A	N/A	
Decision-maker specific	0.629	1.286	
Reputation	0.079*	2.286	
Capacity	0.149	2.000	
Financial capacity (Receivables)	----	1	

*** Significant at the 0.01 level

** Significant at the 0.05 level

* Significant at the 0.10 level

The exponentiated regression coefficient Exp(B) related to the significant categories provides an estimate of the relative difference between the categories. The regression model set the Exp(B) value for *financial capacity (Receivables)* to 1, which the other categories are referenced against. For the other categories, an Exp(B) value above 1 indicates that one can expect an increase in the

number of disruptions, whereas a value below 1 indicates that one can expect a decrease in the number of disruptions compared to the reference category. E.g. one can expect an increase in the number of supply chain disruptions of 1042.9% when moving from *Financial capacity (Receivables)* to *catastrophic* (11.429-1).

The Exp(B) values for *catastrophic*, *supplier operational* and *legal, bureaucratic and regulatory* of *11.429, 10.571* and *7.143* are comparatively higher than for the other categories, indicating that one can expect more disruptions allocated to these categories compared to the others. This supports the initial comparison between the categories as shown in figure 12.

To discern if this difference in effect on number of supply chain disruptions allocated was not due to chance variation, a pairwise comparison of the estimated marginal means based on the linear predictor between the sub-categories was done. Only the categories that yielded a statistically significant result in the regression model was evaluated. The result of the analysis is displayed in table 13.

Table 13: Pairwise comparison of estimated marginal means across the sub-categories of supply chain risks.

Category(I)	Category(J)	Mean difference(I-J)	Sequential Sidak Sig	Result
Catastrophic	Political risk	0.792	0.364	No support H_2
	Supplier operational	0.081	1.000	No support H_2
	Demand	0.876	0.184	No support H_2
	Transportation	0.969	0.079*	
	Legal, bureaucratic and regulatory	0.485	0.998	No support H_2
	Infrastructure	0.877	0.184	No support H_2
	Reputation	1.621	0.000***	

*** Significant at the 0.01 level

* Significant at the 0.10 level

The analysis reveals that the differences between *catastrophic* and *political risk, supplier operational, demand, legal, bureaucratic and regulatory* and *infrastructure* could not be considered statistically significant. In particular, the difference between *catastrophic* and *supplier operational* is negligible with a difference in estimated marginal mean of only *0.081*.

Furthermore, the analysis shows that even though *catastrophic* have had a statistically significant effect on the number of supply chain disruptions allocated and holds the highest Exp(B), it was

not possible to determine that *catastrophic* has had a larger effect on the number of supply chain disruptions allocated compared to *political risk*, *supplier operational*, *demand*, *legal*, *bureaucratic and regulatory* and *infrastructure.*

Thus, it is not possible based on the analysis to conclude that *catastrophic* has been the most predominant source of supply chain disruptions. However, it can be concluded that c*atastrophic* has been one of the most common sources of supply chain disruptions. Consequently, the analysis only lends partial support to:

H_2: *Catastrophic risks have been the most predominant source of supply chain disruptions during the last decade.*

4.4 Risks internal to the supply chain

In order to examine if risks *internal to the supply chain* have in total been the most common source of supply chain disruptions, the number of disruptions allocated to each of the three main-categories was compared as shown in figure 13. The most prominent main-category was risks *internal to the supply chain* with 223 (50 %) of the disruptions allocated. Risks *internal to the supply chain* was then followed by risks *external to the supply chain* with 143 (32%) and finally risks *internal to the firm* with 79 (18 %) of the disruptions.

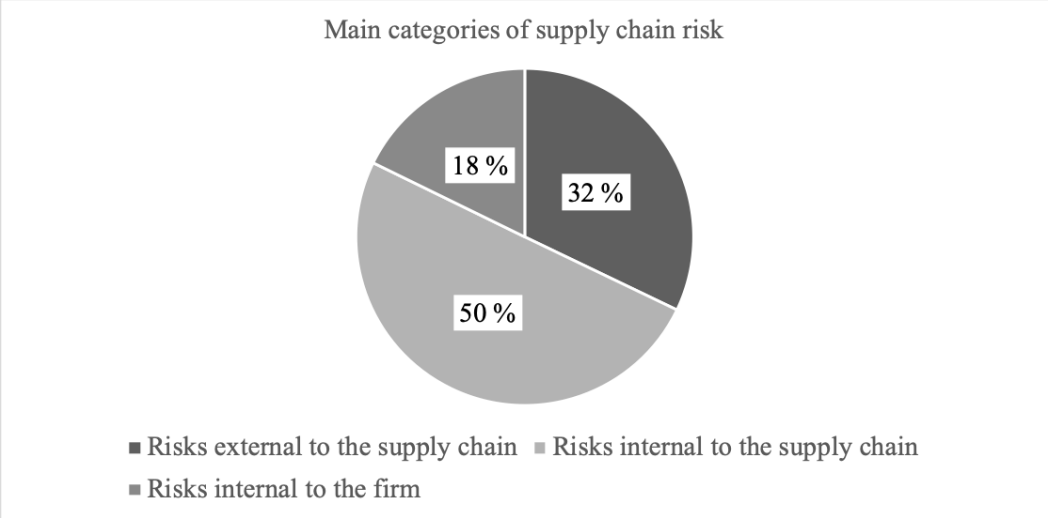

Figure 13: Supply chain disruptions across the three main-categories of supply chain risks.

Treating the number of disruptions per category per year as a count, the data can be analysed to assess whether one category had a statistically significantly larger effect on the number of

disruptions allocated than the others. A negative binomial regression with the number of disruptions as the dependent variable main-category as the independent variable yielded the following results (table 14). Year was also added as a covariate.

Table 14: Negative binomial regression across the main-categories of supply chain risks.

Category	Sig.	Exp(B)	Result
Internal to the supply chain	0.000***	2.823	Supports H_3
External to the supply chain	0.000***	1.810	
Internal to the firm	------	1	

*** Significant at the 0.01 level

The modelling of all three main-categories yielded statistically significant results at the *0.01* level of significance, indicating that all the three main-categories has an explanatory effect on the number of disruptions allocated. Risks *internal to the firm* serves as a reference to compare the two other categories against and is set to 1. The Exp(B) value of risks *internal to the supply chain* of *2.823* is higher than the corresponding value for risks *external to the supply chain* of *1.810.* Consequently, one can expect a larger increase in the number of supply chain disruptions allocated when moving from risks *internal to the firm* to risks *internal to the supply chain*, than when moving from risks *internal to the firm* to risks *external to the supply chain.* Year did not yield a statistically significant effect on the number of supply chain disruptions with a p-value of *0.121*.

To discern if this difference in effect on number of supply chain disruptions allocated was not due to chance variation, a pairwise comparison of the estimated marginal means based on the linear predictor between the main-categories was done. The result of the analysis is displayed in table 15.

Table 15: Pairwise comparison of estimated marginal means across the three main-categories of supply chain risks.

Category(I)	Category(J)	Mean difference(I-J)	Sequential Sidak Sig	Result
Internal to the supply chain	External to the supply chain	7.877	0.001***	Supports H_3
	Internal to the firm	14.112	0.000***	Supports H_3

*** Significant at the 0.01 level

The pairwise comparisons reveal that the differences between risks *internal to the supply chain* and risks *external to the supply chain* and risks *internal to the firm* were statistically significant

at the *0.01* level. Also, the positive difference in estimated mean of *7.877* and *14.112* implies that risks *internal to the supply chain* has had a larger effect on the number of supply chain disruptions than the two other main-categories of supply chain risk.

The analysis shows that risks *internal to the supply chain* has had the largest effect on the number of supply chain disruptions allocated, thus lending support to:

H_3: *Risks internal to the supply chain have been the most common source of supply chain disruptions during the last decade.*

4.5 Infrastructure Risks

In order to test whether there has been a developing trend in relation to disruptions originating from *infrastructure* risks an analysis of the number of disruptions per year allocated to the category was conducted. Observing how the number of disruptions has changed from 2009 to 2018 (Figure 14) there has seemingly been a positive trend during the decade. However, it is not clearly discernible with an increase between 2009 and 2011, before a decline from 2011 until 2013, and then again, an increase between 2014 and 2018.

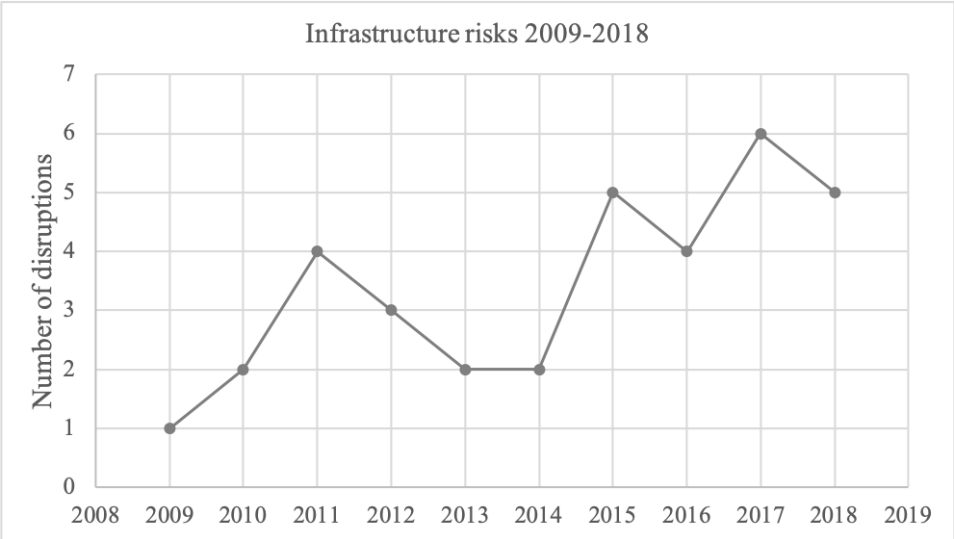

Figure 14: Supply chain disruptions caused by infrastructure risks from 2009 to 2018.

To test whether there has been a positive trend or not, a Modified Mann-Kendall test was applied to the yearly number of supply chain disruptions allocated to *infrastructure* risks from 2009 to 2018. The result of the test is displayed in table 16.

Table 16: Mann-Kendall trend test of infrastructure risks.

Category	Sig.	S	Result
Infrastructure	0.022 **	26	Supports H_4

** Significant at the 0.05 level

The test yielded a p-value of *0.022* indicating a trend at the *0.05* level of significance. The corresponding Mann-Kendall statistics(S) of *26* confirms that the trend has been positive which in turn lends support to:

H_4: *Infrastructure risks have increased as a source of supply chain disruptions during the last decade.*

4.6 Summary

An analysis of the dataset revealed that disruptions arising from risks *external to the supply chain* have not seen a positive trend during the decade, which is contradictory to what was stated in H_1. A comparison between the different sub-categories shows that *catastrophic* risks have been one of the most prevalent sources of supply chain disruptions, but not the most dominant which was stated in H_2 therefore only providing partial support to H_2. Examining the differences between the three main-categories of supply chain risks showed that risks *internal to the supply chain* were in total the most prevalent sources of supply chain disruptions lending support to H_3. Finally, the analysis indicated that disruptions stemming from *infrastructure* risks have increased during the decade, granting support to H_4. The result of the analysis is summarized in table 17. The next chapter will discuss these results using relevant theories and concepts.

Table 17: Summary of the analysis.

Hypotheses	Result
H_1: Risks external to the supply chain have increased as a source of supply chain disruptions during the last decade.	No support
H_2: Catastrophic risks have been the most predominant source of supply chain disruptions during the last decade.	Partial support
H_3: Risks internal to the supply chain have been the most common source of supply chain disruptions during the last decade.	Support
H_4: Infrastructure risks have increased as a source of supply chain disruptions during the last decade.	Support

5 Discussion

Based on a study of 11 504 articles from the Financial Times database, 445 samples describing supply chain disruptions were retrieved. Starting from a literature review on commonly held views on supply chain risk within the scholarly literature and risk management communities, four hypotheses were formulated. An analysis of the 445 samples gave support for or refuted the hypotheses. The results of this exercise provide insight on what risks have been the key sources of supply chain disruptions during the last decade, contrasted against what the literature and risk management communities have focused on as important risks in the same period. The results do not portray the magnitude of losses incurred by firm due to supply chain disruptions. Neither does it quantify to which degree the supply chain was affected. It is reasonable to assume that an earthquake destroying a production plant will result in more severe consequences for the normal operation of the supply chain and the firm, then late delivery of parts. To the authors' knowledge, only the studies of Hendricks and Singhal (2003, 2005a, 2005b, 2014) and Wagner and Bode (2006, 2008, 2009) presents large scale empirical evidence on the magnitude of loss from supply chain disruptions and how supply chain disruptions have affected supply chain performance. Nevertheless, the results in this study aims at portraying a picture of what risks have been, or are evolving to be, the main sources of supply chain disruptions in terms of frequency. The authors believe this insight might help managers and practitioners to direct focus to the risks which actually pose a threat to their supply chains, and as such help them to better assess risks to their supply chain.

Looking at the main-categories of supply chain risk the results show that risks *internal to the supply chain* proved to be the most predominant source of supply disruptions. Risks *internal to the supply chain* entails risks factors that have been described as the traditional "bread and butter" concerns of supply chain managers (Wagner and Bode, 2009). These risks include demand- and supply side risk as well as transportation delays such as carrier breakdowns and port strikes that prevent the flow of materials. In particular, this study revealed that s*upplier operational, legal, bureaucratic and regulator*, *demand* and *transportation* as one of the most common risks *internal to the supply chain.* This aligns with a previous study by Wagner and Bode (2009) where the traditional demand- and supply side risks were considered the most prevalent. *Supplier operational* as a common source of disruptions also resonate with the

findings of Hendricks and Singhal (2005a). In their study they found that disruptions related to events such as parts shortages accounted for 539 of the disruptions recorded, whereas only 44 disruptions could be tied to risks such as extreme weather which is included in risks *external to the supply chain*.

A possible explanation for the high number of disruptions attributed to risks *internal to the supply chain* may lie in the focus on efficiency and cost reduction in supply chains. In a bid to increase the efficiency and reduced the cost of their supply chain operations, firms have not only left supply chain more open to disruption from sources *external to the supply chain* but also left them susceptible to risks *internal to the supply chain.* By implementing efficiency measures such as Just-In-Time and Lean, firms have reduced the slack in the supply chain by removing stock on hand (Steck and Kumar, 2009; Tang and Musa, 2011). A potential negative consequence of this development is the reduced ability to mitigate the effects of supply chain disruptions such as late deliveries and quality issues. These sentiments might explain why the results of this study show that risks *internal to the supply chain* to have been the most predominant source of supply chain disruptions.

Another contributing factor for seeing risks factors *internal to the supply chain* as the most common source of supply chain disruptions might be the profound attention given to high profile risks *external to the supply chain* by risk management communities and the media. Studies show that the more available the information about a risk is, the easier it is to recognize it, which in turn increases the chance of overestimating the probability of the risk (Renn, 2017). This rationale aligns with widely accepted psychologist rationale labelled “availability bias”, and is addressed by both Stauffer (2003) and Wagner and Bode (2008) who stresses that the more trivial risks *internal to the supply chain* tend to be forgotten in favour of high visibility external events. With the intense news coverage on extreme events, it seems likely that managers and practitioners have overestimated the probability of risks *external to the supply chain* and directed their attention accordingly, perhaps at the cost of less attention given to risks *internal to the supply chain.*

This explanation seems even more likely when considering firms limited reporting regimes on supply chain disruptions. BCI (2018) surveyed firms on their supply chain disruption reporting procedures and found that as of 2018 only 30% conducted firmwide reporting and 27% did not

report disruptions at all. Additionally, the survey showed that only 38% of the respondents said that their organization employed technology to predict, monitor, record and report on supply chain disruptions. This indicates that a large number of managers and practitioners lack empirical data on what have caused supply chain disruptions to their supply chains. This observation implies that other sources of information are used when assessing risks to their supply chain. The lack of empirical data lends support to the notion that "availability" bias has played a role in directing the focus of managers and practitioners towards risks *external to the supply chain* which has been the focus of the media especially.

Risks *external to the supply chain* have gained considerable attention from both academia and practitioners over the last decade. Not unwarranted, as there is evidence that supply chains have become more susceptible to disruption from external events as they have become more globalized. Based on this notion one would expect that disruptions associated with risks *external to the supply chain* have increased. However, this study did not find that the number of supply chain disruptions related to risks *external to the supply chain* has increased during the decade. This might seem counter-intuitive, as there appears to be a substantial number of events such as extreme weather and political turmoil plaguing the global economy. In particular, the threat political shifts pose has gained momentum as a significant source of disruption to the supply chain in parts informed by the emergence of geopolitics exemplified with Russia's annexation of Crimea and the recent trade wars between the US and China.

One possible contributing factor explaining why there has not been an increase in disruptions related to *risks external to the supply chain* might be that the SCRM processes of firms have been effective against these risks. In light of the strong focus of scholarly literature and the risk management communities, it is reasonable to believe that managers have directed their attention to these risks. This might help explain why the frequency of supply chain disruptions related to these risks has been relatively constant over the decade despite the seemingly increased threat posed by these risks. Also, the potential dreadful consequence of single disruption originating from *external to the supply chain* might explain why focus has been directed at these events. E.g. a fire might have much more disastrous consequences for the firm than a case of late delivery, as seen in the case of Ericsson where a fire at a key production plant caused a $400 million loss which contributed to Ericsson withdrawal from the mobile phone industry (Norrman and

Jansson, 2004; Chopra and Sodhi, 2004). Naturally, such events will draw the attention of managers and help direct the SCRM efforts towards these risks. The attention given to these risks might in turn have contributed to creating supply chains which are increasingly resilient against risks *external to the supply chain.*

To further investigate the discrepancy between the sentiment of risks *external to the supply chain* as an increasingly common source of supply chain disruptions, and the findings in this study which showed no increase, a Mann-Kendall trend test on the percentwise distribution of supply chain disruptions between the three main-categories over the last decade was conducted. The analysis yielded the following results.

Table 18: Mann-Kendall trend test of the percentwise distribution across the main-categories of supply chain risk.

Main-Category	Sig.	S
External to the supply chain	0.025*	-26
Internal to the supply chain	0.640	7
Internal to the firm	0.127	18

** Significant at the 0.05 level

The result of the analysis quite interestingly reveals that risks *external to the supply chain* have seen a negative trend at the *0.05* level of significance with a p-value of *0.025* and a S-value of *–26.* No trend was found for the other two main-categories. This result shows that the proportion of supply chain disruptions attributed to risks *external to the supply chain* have decreased, which implies that the combined share of disruptions which have been caused by risks *internal to supply chain* and risks *internal to the firm* have increased. This pattern can also be seen in the annual reports issued on supply chain disruptions by Resilinc (Resilinc, 2019). Looking at the top five most common recorded sources of supply chain disruptions from 2014 -2018 on a global scale across several industries, the percentage of events which can be tied to risks *external to the supply chain* have decreased from 22% to 15%, whereas disruptions related to risks *internal to supply chain* and risks *internal to the firm* combined have increased from 19.8% to 36% (Resilinc, 2017; Resilinc, 2019).

A potential explanation for this development might be the global financial crisis that occurred in 2007-2008. During the beginning of the decade (2009-2013) supply chains were still struggling with the aftermath of the financial recession which resulted in a high number of disruptions related to volatile asset prices and supplier insolvencies caused by macro-economic factors *external to the supply chains.* During the decade supply chains recovered and a decreasing proportion of disruptions were caused by risks related to risks *external to the supply chain.* At the same time, new threats to supply chains such as sustainability and reputational issues were introduced, contributing to an increase in the proportion of supply chain disruptions caused by risks *internal to the supply chain* and risks *internal to the firm*.

At the sub-category level, academia has stressed the importance of high impact events such as terrorism and earthquakes. The findings partially align with this, with *catastrophic* as the most predominant in terms of the absolute numbers of disruptions allocated. However, it was not possible to conclude that it had been larger than *political risk, supplier operational, demand, infrastructure* and *legal, bureaucratic and regulatory.* Despite the findings not unequivocally supporting *catastrophic* risks as the most prevalent sources of supply chain disruptions, the findings show that these risks have been one of the most frequent sources of disruptions to supply chains. This also resonates with what has been the focus of risk management communities such as the WEF. WEF has consistently rated *catastrophic* risks such as extreme weather events and natural disasters among the top five risks to the global economy in terms of likelihood and impact over the last decade (WEF, 2018).

Biases in the data source of the study might also help explain why *catastrophic* risks came out as one of the most common sources of supply chain disruptions. It is plausible that the Financial Times might be biased towards headline-grabbing news on *catastrophic* events such as natural disasters, political turmoil, asset price collapse and conflicts. Studies have shown that media, often unconsciously, is affected by biased which affects both what news are presented but also how the news is presented (Baron, 2006). Baron (2006) further argues that journalists might introduce biases in their reporting to the news which could promote their careers. There is a reason to believe that the more "sensational" *catastrophic* events are more likely to be presented on the front page compared to the more mundane stories on e.g. supplier issues. Following this line of reasoning, it is possible that some of the supply chain disruptions associated with

catastrophic events might actually have stronger causality to more trivial, but less headline-grabbing events such as part shortages. However, in a career promoting move, journalists might skew their news towards *catastrophic* events, thus contributing to a large number of supply chain disruptions attributed to *catastrophic* risks found.

Despite the potential biases introduced through the data source, there is still evidence that *catastrophic* events have been a significant threat to supply chains. The infamous 2011 Great East Japanese earthquake (GEJE) serves as an example of how *catastrophic* events have disrupted supply chains. Hendricks, Jacobs and Singhal (2017) found that firms which experienced supply chain disruptions during the GEJE lost on average 3.7% of their shareholder wealth. Furthermore, Todo et al. (2015) calculated that as much as 90% of the output loss caused by the GEJE could be attributed to supply chain disruptions. This example shows how *catastrophic* risks can severely affect the supply chain performance. One possible contributing factor why the study found these risks to be one of the most common sources of supply chain disruptions can be found in statistics from the Centre for Research on the Epidemiology (2019) of disasters. Even though there has been a slight decrease in the number of natural and man-made disaster the last decade, the number is still worryingly high with 4625 man-made disasters and 4898 natural disasters which have occurred over the last decade. The large number of disasters in conjunction with supply chains having become more globalized and more exposed, might contribute to explain why *catastrophic* stood out as one of the most prominent sources of supply chain disruptions in this study (WEF, 2012a).

Another focus of risk management communities have been that of terrorism. The WEF has featured terrorism among the top 5 in their supply chain risk surveys as well as in their most prominent report *The global risk report* which has featured terrorism as one of the major risks to the global economy consistently from 2009-2018 (WEF, 2009, 2010, 2011, 2012a, 2012b, 2013a, 2013b, 2014, 2015, 2016a, 2016b, 2017, 2018). Likewise, Allianz Risk Barometer reports that respondents in 2018 are more worried about terrorism than before (Allianz, 2018). This strong focus on terrorism doesn't align with the findings in this study. Table 19 displays *catastrophic* risks unpacked into more definite subcategories.

Table 19: Catastrophic risks unpacked.

Sub-categories of catastrophic risks	Number of supply chain disruptions
Weather-related (Natural disasters, adverse weather)	47
Major accident (fire, explosion)	19
Manmade deliberate (terrorism, war, theft)	8
Other	6

Weather-related events account for almost 58.75 % of the disruptions in the *catastrophic* category, which resonate with what risk communities have focused on. However, terrorism, war and theft only account for 10 % of the disruptions. This doesn't align with the focus of some risk communities. A potential explanation for this discrepancy can be found in the psychology literature. Studies have shown that people tend to stigmatize risk sources that are associated with especially bad outcomes (Kunreuther and Heal, 2003). A classic example of this stigma is public opinion against nuclear power plants. Even though it is commonly accepted that very few accidents are related to nuclear power production, the public opinion is very negative towards it because of the negative association with the word nuclear and the potentially devastating effect of an accident (Whitfield, Rosa, Dan and Ditz, 2009). The same stigma might explain why risk communities seem to focus on terrorism, whereas the findings in this study show that very few disruptions to supply chains can be accounted for by terrorism. The potential dreadful consequence of terrorism might have warranted a too strong emphasis on risks to supply chains caused by terrorism, possibly causing risk communities to overrate the importance of it.

The findings suggest that there has been an increase in the amount of supply chain disruptions caused by *infrastructure* risks such as IT outage, data viruses and hacking. This aligns with what academic and risk communities have focused on. The Business Continuity Institute (2009-2018) has consistently reported "Unplanned IT or telecommunications outage" as one of the most common disruptions to supply chains. Likewise, Allianz Risk Barometer (2018) rate cyber incidents as the second most important corporate peril for the year ahead. A likely explanation for the increase in supply chain disruptions caused by *infrastructure* risks is the increased dependence on ICT systems in supply chains. In order to stay competitive in the global economy, firms have transformed their supply chain using computer-based managing systems such as enterprise resource planning (ERP) systems and automated processes. The digital transition has

moved the information flow away from physical processes using paper and telephone into one using digital transactions and databases (Boyes, 2015; Acar, Zaim, Isik and Calisir, 2017). This transition has allowed firms benefits such as easier information sharing, cost reduction and improved customer satisfaction, but as this study shows also left supply chains increasingly susceptible to disruptions (Colicchia et al., 2019).

The increase in disruptions stemming from infrastructure risks also highlight the managerial challenges facing firms that are dependent on IT systems. Researchers have noted that significant efforts have been invested in reducing the risks associated with the physical aspect of the supply chain, but less attention has been given to cyber aspects (Davis, 2015) The increase in supply chain disruptions caused by *infrastructure* risks shown by this study lends support to this notion, and highlights the need for a supply chain perspective on cyber-risk (Colicchia et al., 2019).

A common division of *infrastructure* risks is unplanned IT or telecom outages and cyber-attacks including data breaches (Donadoni et al., 2019; BCI, 2018). An interesting observation can be made when granulating the findings into these two categories as shown in table 20.

Table 20: Infrastructure risks unpacked.

Sub-categories of infrastructure risks	Number of supply chain disruptions
Unplanned IT outage (Server shutdowns etc.)	16
Cyber-attacks and data breaches (Hacking, virus)	6
Other	12

Unplanned IT outage has been the cause of more than twice the number of supply chain disruptions compared to cyber-crime. This observation is in line with the findings of some academics and risk management communities who rated unplanned IT or telecommunications outage as more important than cyber-attacks (Donadoni et al., 2019; BCI, 2018). Other organizations, including the WEF, have focused more on cyber-attacks as a significant threat to business and the global economy (WEF, 2018). This study indicates that although cyber-attacks pose a significant threat to supply chains, disruptions caused by IT failures have been a more common source of supply chain disruption. This insight suggests that supply chain practitioners and academics give a better prediction on the sources of supply chain disruptions than risk experts that look at risks at a global level such as the WEF. This is understandable due to the

difference in scope. WEF looks at risks to the global economy as a whole, whereas bodies such as the BCI and supply chain researchers focus specifically on risks to supply chains.

Even though there are relatively few samples associated with unplanned IT-outage and cyber-attacks, a trend test of the two makes for some interesting observations. Investigating the presence of any trends associated with the number of supply chain disruptions caused cyber-attacks with a Mann-Kendall trend test, yielded no positive trend. This is surprising given the growth in cyber-crime and the continued digitalization of the supply chains. However, for unplanned IT outage, a Mann-Kendall trend test showed a significant positive trend at the *0.10* level with a p-value of *0,063* and S-value of *20*. The increase in the number of supply chain disruptions attributed to unplanned IT outage corresponds with the changes in the IT infrastructure that have taken place over the last decade. Organization are increasingly replacing their local based servers for cloud-based servers (Boyes, 2015). A consequence of this is an increased dependence on the smooth operation of global communication and networking services (Boyes, 2015). This increased reliance on servers provided through the internet has naturally been a concern in relation to cybersecurity and cyber-attacks, but might also have contributed to an increase in supply chain disruptions caused by IT outages.

The increased use of external services might also be a contributing factor explaining why no trend could be found for supply chain disruptions associated with cyber-attacks. As firms are moving more of their IT system off premise and into the cloud, they become the end user and not necessarily the direct recipient of the cyber-attack. An example of this is the case of the Chinese hacker group “Red Apollo” who launched a large-scale cyber espionage campaign by targeting cloud services rather than firms directly (Bond, 2018). Given this premise firms might tend to only announce the cyber-attacks that directly have targeted their system, as in the case of Norsk Hydro. If this notion holds true, it would contribute to explain why there has been a positive trend related to unplanned IT outage, whereas no positive trend was detected for cyber-attacks. Another possible explanation is that businesses have increasingly become proficient at mitigating cyber-attack that affect their supply chain. Cyber-attacks and cyber-security have become a top priority for companies which might have contributed to stemming the increasing tide of cyber-attacks (Mckinsey&Company, 2018). However, this seems less likely given that the report also

indicated that firms considered themselves unprepared against cyber-risks (Mckinsey&Company, 2018).

Next, the study will be concluded with a summary of the findings aimed at answering the research question together with the limitations of the study, contributions to the field of research, managerial implications of the study and suggestions for further research.

6 Conclusion

The major aim of this study has been to provide empirical evidence on which risks have been the main sources of supply chain disruptions during the last decade in a bid to answer the research question:

What have been the main sources of supply chain disruptions over the last decade, and do observed patterns correspond with expectations put forward in the scholarly literature and the risk management communities?

There seem to have been an overly strong focus on risks *external to the supply chain* in academia and risk communities. Although this study revealed that a substantial amount of supply chain disruptions could be traced back to risks *external to the supply* chain the more traditional risks *internal to the supply chain* accounted for the largest number of disruptions. With the most prominent risks *internal to the supply* being operational challenges at suppliers. The same pattern can be found in the earlier works by Hendricks and Singhal (2003, 2005a, 2005b) and Wagner and Bode (2006, 2008). Although these studies examine other aspects than this study, they portray the same picture of risks *internal to the supply chain* as a frequent source of supply chain disruptions. In addition to disruption attributed to *supplier operational, legal bureaucratic and regulatory risks* emerged in second place based on the number of disruptions allocated amongst the risks *internal to the supply chain*. This is not surprising given the nature of 21. century supply chains which span across national borders and various jurisdictions.

Literature and risk management communities proved to be accurate with their focus on *catastrophic* risks. Even though this study was not able to prove unambiguously that *catastrophic* had been the single most predominant source of supply chain disruptions, it was still the largest sub-category of supply chain disruptions in terms of number of disruptions allocated. *Catastrophic* events both related to natural and man-made disasters have garnered considerable attention, especially within risk management communities. This is not surprising given the high-profile natural disasters and terrorist attacks that have occurred during the decade. However, the findings show that only a small proportion of the recorded supply chain disruptions could be traced back to terrorism, by far outweighed by disruptions related to natural catastrophes and adverse weather.

This study also revealed that there had been an increase in supply chain disruptions related to *infrastructure* risks over the decade, which were proposed both by academic literature and risk management communities. Although the focus on *infrastructure* risks as an increasing threat to supply chains proved to be justified, there seems to be a difference in opinion regarding the relative importance of cyber-attacks and unplanned IT outages. While some have focused on cyber-attacks as a threat towards supply chains others have emphasized on unplanned IT outages. Granulating the disruptions related to *infrastructure* risks into unplanned IT outage and cyber-attacks revealed that unplanned IT outage was the most prominent source of supply chain disruptions of the two, lending support to those focusing on such risks.

The findings in this study have highlighted which risks have been the main sources of supply chain disruptions during the last decade, but also how these patterns resonate with the focus of supply chain management literature and risk management communities within the same period. Both risk management communities and academia have focused on risks *external to the supply chain.* Even though there has not been an increase in supply chain disruptions associated with these risks, their focus is justified with a large amount of devastating disruptions stemming from risks *external to the supply chain.* Also, the more trivial risks *internal to the supply chain* have been an area of interest both in the scholarly literature and risk management communities. Especially academics and organizations such as the BCI aimed at assessing risks to supply chain were accurate with their focus on these more mundane risks as a serious threat towards the normal operation of supply chains. Organizations looking at risks at a more aggregated level, such as the WEF, have focused more on rare high impact c*atastrophic* events and less on the more common day risks. The findings show that this focus is not without merit, as c*atastrophic* risks proved to one of the most common sources of supply chain disruptions over the last decade. *Infrastructure* risks have been the focus of both academia and the risks management communities. With an increase in supply chain disruptions associated with these risks this focus has proven to be accurate. Generally speaking, academic's and organizations which are looking at risks especially at supply chains proved to be more accurate with their expectations on sources of supply chain disruptions compared to organizations assessing risk to the global economy as a whole. However, no single author, or risk management community was able to grasp all the disruptive patterns that were revealed through this study. This observation comes to show that no single source of information is able to grasp all the patterns and emerging trends of supply chain

disruptions, which emphasize the importance of using several sources of information when assessing risks to a supply chain.

A limitation of this study is the dependency on secondary data. The Financial Times news articles introduced biases, for this study most notably "newsworthy" disruptions. This might explain why *catastrophic* risks came out as one of the most prominent sources of supply chain disruptions. However, more mundane risks under the main-category *internal to the supply chain* accounted for the cumulatively largest amount of supply chain disruptions. This indicates that even though the Financial Times will be naturally biased towards typically "news worthy" disruptions such as terrorism and natual disasters, they are still able to cover several dimensions of risks. An additional limitation is the Financial Times tendency to be skewed towards larger firms, such as Apple and Samsung. However, the samples retrieved also contains disruptions related to smaller firms. Thus, the authors believe the results should also be considered by managers of smaller firms, but with the biases of the data source taken into account. Another limitation of this study is that it only looks at supply chain disruptions at an aggregated level. No divisions have been made between different industries or geographic regions. Consequently, no conclusions can be drawn towards the key sources of supply chain disruptions within any given industry or geographic location. Finally, the study has only looked at the frequency of disruptions to discern the main sources of supply chain disruption. No attempt has been made to quantify the magnitude of losses incurred, or the consequences to the normal operation of the supply chain following a disruption. The results have to be interpreted as guide towards current patterns and emerging trends on supply chain disruptions, and as such should be complemented with internal reporting within each firm on the sources of supply chain disruptions towards their specific supply chain.

This study provides novel contributions to the supply chain risk management (SCRM) field of research in three ways. First, it is to the authors' knowledge the first study which tries to quantify the most prominent sources of supply chain disruptions in terms of the number of disruptions using large scale empirical data other than surveys. The studies of Hendricks and Singhal (2003, 2005a, 2005b, 2014) use a similar method for the data collection, but analyse the data to assess the consequences of supply chain disruptions in terms of negative effect on shareholder wealth and operating performance. This study, on the other hand, uses the data to investigate current

patterns and future trends on sources behind supply chain disruptions, contrasted against commonly held views put forward in the scholarly literature and the risk management communities. By doing so this study not only contribute by displaying the key sources behind supply disruptions, but also assesses the accuracy of the literature and risk reports on the subject. Second, the research responds to the lack of empirical evidence on sources of supply chain disruptions, thus helping close the literature gap identified by Sodhi et al. (2012) concerning limited empirical research within the field of SCRM. Third, it responds to the call to test the supply chain risk typology put forward by Louis and Pagell (2019), and by doing so contributes to the transition from a typology towards a taxonomy on supply chain risks.

Several managerial implications can be deduced from this study. First and foremost, the results highlight that in order to portray an accurate picture of the supply chain risks faced by a firm, several sources of information have to be utilized. Both internal reporting, scholarly literature and risk reports are necessary to capture the current and future trends on supply chain disruptions. Additionally, managers must keep in mind the presence of stigma and biases when assessing risks to their supply chain. Especially, within some risk management communities there seems to be a bias towards risks which are highly profiled in the news, with only limited empirical evidence that these risks pose a threat to supply chains. Also, risks which are related to especially bad outcomes, such as terrorism, seem to receive an overly large amount of attention even though these according to this study have only been the source of very few supply chain disruptions. The last recommendation is for managers to be mindful of the continued threat posed by the more traditional risks *internal to the supply chain*. This study suggests that today's supply chains are still vulnerable towards disruptions from these well-established risks including late deliveries and part shortages. An observation which highlights the need for mangers to acknowledge the importance of frequent "everyday" disruptions and strive to prepare their supply chains for these risks.

Volatility in the business environment is not likely to decrease in the foreseeable future. As supply chains have evolved, they have become exposed to new risks along the way which have not been predicted by academia and practitioners. The 2001 9/11 terrorist attacks marked the start of a decade plagued by high impact events which threatened to undermine supply chain performance. The decade was concluded with the global financial crisis of 2008/2009 which saw

asset price collapse resulting in suppliers and customers going bankrupt. The first part of the following decade was tormented by adverse weather and natural catastrophes such as the 2010 Iceland volcanic eruption and hurricane Sandy which in 2012 caused massive disruptions to supply chains all over the world. The later part of the decade has seen the increase in political turmoil with the inauguration of Trump and Great Britain embarking on a political journey towards leaving the EU introducing new threats to supply chains. The last decade has also seen a development towards supply chains becoming increasingly dependent on ICT, exposing them to cyber-crimes and system failures. There is no indication that this development will stagnate, suggesting that the next decade will be characterized by supply chains becoming even more digitalized and further exposed to disruptions in the digital domain. However, underlying these developments, is the constant but often overlooked threat posed by less profiled events such as late deliveries and quality issues. The classical study by Henricks and Singhal (2005b) saw these risks as the most common sources of supply chain disruptions between 1992 and 1999. Wagner and Bode (2009) found a similar pattern in the following decade using large-scale surveys among supply chain managers. The last decade was no exception, with the results of this study revealing that risks *internal to the supply chain* was the most prominent source of supply chain disruptions. There are no signs that this pattern will change for the next decade either. Both this study, and reports from Resilinc (2017, 2019) show that the combined proportion of supply chain disruptions caused by risks *internal to the supply* chain and *internal to the firm* are increasing. Although disruptions caused by these risks might not pose an existential threat to business, the cumulative cost might be enough to lose the competitive edge. This shows that in the strive to prepare for risks which may pose a threat to the firm's existence, the everyday problems are often forgotten. There is no doubt that there is great potential in increasing the focus on these risks in the SCRM processes. Firms which are successful in implementing measures to reduce disruptions from the more common supply chains risks will be able to achieve a more stable operation of their supply chains. With stability comes lower production cost and shorter time to market, which in turn will help increase the competitive ability of the firm

Several areas for further research are identified. No samples related to the c*ultural* and *problem specific* categories were retrieved. The authors believe this to be in part attributed to the definitions of the categories from Louis and Pagell (2019) being too abstract, thus being difficult to use when categorizing a supply chain disruption. Consequently, the typology of Louis and

Pagell (2019) should be further tested using a different data source to see if similar patterns are recognised. Furthermore, future research should attempt to compare supply chain disruptions across regions and industries. This study has only looked at disruptions at an aggregated level, without considering if some risks are more predominant in one region/industry compared to another. Research looking at such comparisons would contribute to give managers across the globe and industries an even more accurate picture of which risks their supply chains are facing. Moreover, further research should be aimed at assessing the impact of the different categories of supply chain disruptions in terms of monetary losses, closing the gap between the work of Hendricks and Singhal (2003, 2005a, 2005b, 2014) and this study. Such a study would provide managers with a foundation for assessing risks to their supply chain both in terms of likelihood and impact.

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Appendixes

Appendix A

Appendix A: Supply chain risk categorisation. Retrieved from Louis and Pagell (2019)

Risks internal to the supply chain.

Risk	Definition	Risk factors
Infrastructure	Arises from unwanted failure caused by intentional or unintentional acts associated with the infrastructure (e.g. IT, vehicles) maintained by a focal firm to execute internal or external supply chain operations	Unavailability of information with suppliers, IT breakdown, bug/hackers, security of IT, incompatible IT systems, denial of service, equipment failure, vandalism at vehicles
Strategic	Arises from unwanted events that can negatively affect the implementation of a focal firm's business strategy	Not effective change management, lack of knowledge of SCM benefits, outdated culture
Problem-specific	Arises from the complexity associated with multiple dimensions of risk decision-making such as long-term planning, goals and constraints, and interrelationship among risks	Interrelationship among risks, long-term planning, goals and constraints
Decision-maker specific	Arises from individual or group level attributes within the organization	Bounded rationality, shortage of knowledge and experience, cognitive abilities
Reputation	Arises from unwanted events that can impose a reputational damage to a focal firm	Poor product quality, shortage of knowledge and experience, cognitive abilities

Capacity	It can arise either from the inflexibility of a focal firm to increase the level of capacity when required, or from capacity's overutilization/underutilization and can result in delays in the production process	Cost of capacity, capacity flexibility, overutilization of capacity, underutilization of capacity
Financial capacity (receivables)	Arises from customers' financial difficulties that can result to delays or interruptions in the money flow towards a focal firm	Delayed payments from debtors, changes in the financial strength customers, bankruptcy of customers, number of customers

Risks internal to the firm.

Risk	**Definition**	**Risk factors**
Supplier operational	It arises from unwanted events that may affect supplier output in terms of quality, quantity and cost which can result in unfulfilled or delayed orders to the focal firm	Quality problems, not anticipated quantity, not anticipated cost, significant variation in lead time, supplier delays, material availability, inappropriate technology
Supplier economic	It arises from unwanted events that may harm a supplier's financial health and can lead to bankruptcy, insolvency or financial instability resulting to unfilled or delayed orders to the focal firm	Difficulties in making payments, financial instability, problems in cash flows, limited number of customers, shortage of raw materials, deteriorated reputation in the market
Cultural	Arises from limited knowledge of cultural idiosyncrasies and language differences among supply chain partners that can result in delays or other failures	Language differences, limited knowledge of cultural differences

Relational	It arises from mistrust, lack of understanding, unnecessary interventions, second guessing among supply chain actors. Their effects are known as "chaos effects" driven by supply chain complexity	Mistrust, lack of understanding, second-guessing, supply chain complexity
Demand	Arises from potential variations between forecast and actual demand	Forecast errors, poor supply chain coordination, poor information sharing, long time horizons, demand volatility, rationing and shortage rumours
Transportation	Arises from unwanted events associated with the delivery of unwanted materials or finished products that can impose delays in their movement	Port strikes, failure in the distribution network, carrier breakdown, failures in the distribution network, inaccessible information about shipment
Inventory	It arises from excessive number of inventories and product value which can impose unnecessary holding costs or excessive product obsolescence	High inventory cost, product value, excessive amount of inventory, rate of product obsolescence
Legal, bureaucratic and regulatory	Arises from litigations against the firm by stakeholders internal to the supply chain (e.g. suppliers, customers)	Litigations by internal to the supply chain stakeholders (e.g. suppliers, customers)
Sustainability	Arises from ecological-, social- or ethical-related violations materializing during the execution of global operations by members of the chain (e.g. suppliers, distributors) leading to harmful reactions from external	CO_2 emissions by chain partners, health and safety violations, child labour, the absence of water treatment, unnecessary placekicking, low wages, not using ecologically friendly waste disposal

	stakeholders (e.g. NGO) that may harm a focal firm	
Financial capacity (Receivables)	Arises from customers' financial difficulties that can result to delays or interruptions in the money flows towards a focal firm	Delayed payments from debtors, changes in the financial strength of customers, bankruptcy of customers, number of customers
Consumer risk	Arises from a focal firms' inability to comply with customers preferences	Difficulties in order fulfilment, changes in customer preferences, delayed delivery, inappropriate quality

Risks external to the supply chain

Risk	**Definition**	**Risk factors**
Competitiveness	Arises from changing market conditions associated with the entry of new competitors or rivalry among current ones, technology changes in product/process, which can result in the loss or reduction of a focal firm's competitive positions	Rapid changes in product/processes technology, lack of information about competitor
Input market	It arises from the inability of a focal firm to acquire anticipated quantity of inputs in the transformation process and can affect the competitiveness and profitability of a supply chain	Lack of alternate suppliers, inability to meet significant quantity increase, variability in quality of raw materials, unexpected raw material increases, scarcity of raw materials
Political risk	Arises from unwanted dramatic changes in the political system	Political turmoil, disturbances from countries interested in the focal firm's project, weak

	that can negatively affect a focal firm's ability to compete	government nationalization, trade tariffs increase, quota restriction, change in taxation
Catastrophic	It arises from high impact – low probability potential events associated with man-made deliberate acts(e.g. terrorism), unintentional man-made acts or natural hazards(e.g. hurricanes, earthquakes, tsunamis)	Terrorism, war, nuclear accidents, earthquakes, hurricanes, tsunamis, floods
Financial market	Arises from changes associated with macroeconomic factors, especially exchange, inflation or interest rates and may ultimately lead to the increase of raw material prices	Changes in exchange rates, high rates of inflation, changes to interest rates

Appendix B

Appendix B: Search strings with corresponding number of articles found per string per year

Search term	Delay AND (procurement OR procuring OR procure OR manufacturing OR production OR shipment OR shipping OR shipments OR deliveries OR delivery OR delivering OR delivered OR vendors OR vendor OR supplier OR suppliers)									
Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
No. Articles	506	521	595	748	719	564	560	621	581	740

Search term	Delay AND (ramp OR roll)									
Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
No. Articles	82	106	86	108	86	77	67	114	98	123

Search term	Shortfall AND (shipment OR shipping OR shipments)									
Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
No. Articles	20	18	31	38	34	13	15	14	9	12

Search term	"Supply chain" AND (Glitch OR Glitches OR Disruption OR Disruptions OR Loss OR Losses)									
Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
No. Articles	105	86	333	199	115	121	138	179	233	305

Search term	(Component OR components) AND (shortage OR shortages OR unavailability OR unavailable OR incompatible OR incompatibility OR delay OR late OR lateness)									
Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
No. Articles	193	219	306	280	228	209	200	242	254	253

Appendix C

Appendix C: Version of Mann-Kendall trend used on the analysed categories

Main-categories	**Trend test used**
Risks external to the supply chain(Absolute numbers)	Mann-Kendall
Risks external to the supply chain (Relative numbers in relation to the therre main-categories)	Mann-Kendall
Risks internal to the supply chain (Relative numbers in relation to the therre main-categories)	Modified Mann-Kendall
Risks internal to the firm (Relative numbers in relation to the therre main-categories)	Mann-Kendall
Sub-categories	**Trend test used**
Infrastrucure	Modified Mann-Kendall
Cyber-attacks (After unpacking infrastructure in discussion)	Mann-Kendall
Unplanned IT and telecommunications outage (After unpacking infrastrucure in discuussion)	Mann-Kendall