

ABSTRACT

Title of Dissertation: SUPPLY CHAIN RISKS, RESILIENCE AND
FIRM PERFORMANCE: AN EMPIRICAL
STUDY

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This dissertation's main focus is the study of supply chain resilience. The two studies investigate the impact of supply chain geographical locations risks and supply chain resilience on performance and of supply chain risks and disruptive events in resilience strategies.

Essay 1 seeks to understand the impact of supply chain resilience strategies on firm's performance. We utilize a cross sectional data sample from 2014 containing detailed manufacturing location risk data and resilience planning at the location level for 313 publicly traded firms. We look at three supply chain resilience cultural traits, business continuity planning, inventory and financial stability. We find that resilience has a positive effect on firm performance.

Essay 2 looks at the impact of two types of supply chain risks (internal and external) and two types of disruptive events (internal and external) in the development of supply chain resilience strategies. We find that external disruptive events have a positive impact on supply chain resilience but internal disruptive events have a negative impact in the development of resilience. However, once a business continuity plan is in place, previous internal disruptive events are associated with more agility.

My findings for both essays contribute to the supply chain resilience literature by empirically testing the impact of resilience on performance and the impact of disruptive events on resilience strategies.

SUPPLY CHAIN RISKS, RESILIENCE AND FIRM PERFORMANCE: AN
EMPIRICAL STUDY

By

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Dedication

This dissertation is dedicated to my father Freddie Martínez, my mother Tomasita Arroyo and my siblings Freddie, Ferdin, Karen and Karol. The love, the education and support that I have received from my family have made me the person that I am. My parents built a home where curiosity and education could be freely pursued and my siblings made the pursuit of those an adventure.

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Chapter 1: Overview

The two essays of this dissertation will focus on supply chain risks and resilience. Supply chain resilience has become an important topic for both researchers and practitioners due to the turbulent environment in which multinational firms have to operate in. Natural disasters, political instability of different countries and economical disasters can impact a firm's capacity to move its products to consumers. Supply chain resilience presents an opportunity to protect the supply chain against disruptions and maintain or even improve firm performance.

Essay 1 of my dissertation analyzes a cross sectional sample of 313 firms across 40 3-digit NAICS code industries and how supply chain geographical risks and resilience impact performance. We framed our hypotheses using Structure-Conduct-Performance paradigm to explain the relationships between our variables and establish our hypotheses. We expect, based on the literature, that resilience will pose a competitive advantage for firms that operate in risky environments, effectively mitigating the impact of risk on performance.

Essay 2 analyzes a cross sectional sample of 159 firms across 3 industries. Essay 2 focuses on the impact of two types of risks and disruptive events, external and internal, on the resilience strategies put in place by the firm. We look at two strategies: business continuity planning and average projected recovery time after a disruption. We pose that the higher the exposure to risks and disruptive events a firm faces, the more likely it will be to have resilience strategies in place in order to cope with the risky environment.

Chapter 2: The Impact of Supply Chain Geographical Location Risks and Resilience on Firm Performance

ABSTRACT

The location of a manufacturing facility can present various risks to the firm's supply chain. The impact of these risks is an understudied area that we address in this essay. Our study uses Resilinc's supplier database to analyze 3,262 manufacturing locations for 313 publicly traded firms across 40 industries. This study examines the impact on firm performance (measured as gross margin) of supply chain geographical location environmental risks (measured as natural disaster risk and geopolitical risk) and firm resilience (measured as financial solidity, recovery time and inventory). Using a linear regression model adapted for industry clusters, we find that natural disaster risk and resilience have a positive impact on performance. A surprising finding shows that frequency of potential disruptions also has a positive impact on firm performance.

INTRODUCTION

On September 20, 2017, hurricane María struck the island of Puerto Rico with its 155 miles per hour maximum winds and lots of water. The Puerto Rico government is still trying to estimate the total impact on the island's economy almost four months after the storm. The current estimate of monetary impact is approximately \$100 billion. The hurricane not only affected the Puerto Rican economy by destroying houses, businesses, the power system in the entire island and structures like roads, bridges and government buildings. Global supply chains have also taken their toll from this big disruption. Examples are the pharmaceutical and medical devices industries. The medical devices industry has an important amount of production in Puerto Rico and about 8% of the medicines consumed in the US are manufactured in Puerto Rico (Aton, 2017). Due to the interruption on production that the factories suffered in the aftermath of the hurricane the Food and Drug Administration is currently tracking 30 critical pharmaceuticals and 50 critical medical devices manufactured solely in Puerto Rico or majorly in Puerto Rico, according to an article published by Scientific American on October 25, 2017 by Aton on EE News.

The current situation in Puerto Rico is only the latest example of what supply chain disruptions can do to firms, industries and countries. Hendricks and Singhal (2003) lead the research on the impact of disruptions to firm performance. They studied public announcements of disruptions to production and deliveries and the impact that these events had on the stock value. They found significant negative impacts that can last up to two years depending on the magnitude of the disruption.

Some studies of supply chain risk focused on assessing the risks with a focus on risk identification and avoidance (Manuj and Mentzer, 2008). More recent studies focus on developing ways to mitigate the risks, accepting that disruptions are part of the supply chain global environment. Supply chain resilience has been proposed as an effective way to cope with the unavoidably risky environment in which firms have to operate (Sheffi, 2005). Is there something that firms operating in Puerto Rico could have done to avoid the impact from hurricane María? Hurricanes are not a new experience to the island, it is situated right in the middle of the hurricane zone. Hurricane María had a historical impact, word of mouth in Puerto Rico says that it has been the worst storm in a hundred years. Can the pharmaceutical and medical devices industries recover fast enough in order to avoid a crisis? Sheffi (2005) suggests that firms with an organizational culture of resilience would be able to find a solution and recover faster than firms with no culture of resilience, but not only during a disruption, resilient firms should be better performing firms due to the benefits that developing resilient processes bring to the firm.

Our study aims to look at the impact of supply chain resilience on firm performance. Using a cross sectional data sample from 2014, we test the impact of three supply chain resilience cultural traits. We use the Structure-Conduct-Performance paradigm to theoretically frame our study and explain our variables and hypotheses.

THEORY AND HYPOTHESIS DEVELOPMENT

The Structure-Conduct-Performance (SCP) paradigm developed by Mason (1939) and Bain (1951), establishes that there is a direct relationship between market structure, firm conduct and performance. Firms respond to the market environment in order to compete and obtain advantage from other firms. The SCP framework has been widely used in the strategy field, as illustrated by Williams and Smart (1993) literature review, to explain the reasons why firms develop certain strategies.

In the current market of global competition, some authors have claimed that competition is no longer firm to firm but supply chain to supply chain, (Trkman et al, 2007; Li et al, 2005). Not surprisingly, the supply chain literature has been intertwined with the strategy literature, (Glassman and Honeycutt, 2002; Hult, Ketchen and Arrfelt, 2007). Blackhurst et al. (2015) utilized the SCP framework to explain the positive impact that supply chain integration has on firm performance.

Another theory that has been used to explain the dynamics of supply chains is Barney's Resource Based View (RBV), (Barney, 1986). Squire, Autry and Petersen (2014) and Blackhurst et al. (2011) applied RBV to explain why firms develop resilience in their supply chains to cope with the risks of disruption that the business environment brings. Similarly, we propose that resiliency is one of the ways that firms respond to a turbulent market environment in order to enhance performance. We combine SCP and RBV with supply chain risk management and resilience literature to frame our hypotheses. We pose that in the modern global environment, there are characteristics to the market beyond market power and entry barriers that affect how a firm can compete in order to obtain higher performance. The risks of

operating in a particular geographical location are an example of these environmental factors. The interpretation of “structure” that we are using, takes into consideration the implications that operating in a global market brings.

Structure

In the SCP framework, “structure” refers to market structure. Traditionally the market environment is measured in terms of market concentration and barriers to entry. Bain defined entry barriers as market conditions that allow incumbent firms to raise prices above the competitive level without attracting entry (Waldman and Jensen, 2007). Making decisions that reduce costs in order to obtain economies of scale is one strategic way to set prices and increase profits.

Holweg, Reichart and Hong (2011) state that cost assessment for global sourcing is highly dependent on cost of production and transportation, but that this assessment is not complete. They posit that supply chain risks are often not included in the cost analysis, leading firms to make decisions to operate in high risk environments. Managing these environments creates additional costs.

Christopher and Holweg (2011) studied how the global economy has changed over 40 years from 1970 to 2010. Using a volatility index, they show that the global economy has been more volatile since the economic crisis of 2007 than it had been historically, indicating that it is less predictable to conduct global business now than it was before the crisis. Since supply chains are the engines that address the movement of goods around the world preserving connectivity between nodes and functions, they propose that the design of modern supply chains should have embedded into it structural flexibility to deal with the economic turbulence.

Knemeyer et al (2009) established that supply chain vulnerability has increased due to globalization and the availability of less slack. By operating in high risk countries in order to seek lower operational costs, the environment in which firms operate has become riskier for many supply chains. In a similar manner, many firms have chosen global networks that operate across different countries and move goods around the world for both production processes and customer deliveries. As global supply chains grow, the probability of facing disruptions also grows, forcing firms to operate in a potentially more disruptive environment. These trends are common across industries, even though the impact of globalization will vary by industry.

i. Supply Chain Risk

The British Dictionary defines risk as the possibility of incurring misfortune or loss. Carvalho and Cruz Machado (2007) state that when it comes to supply chain failures: “the sources of disturbance might be infinite, but the number of failures is finite.” They place supply chain/operational risks as resulting into five possible failures: 1) raw materials shortage, 2) labor shortage, 3) machine capacity shortage, 4) scrap/rework, 5) finished goods not delivered. In our study we consider supply chain risk to be the possibility of a firm incurring loss due to any of the five failures listed above.

Rao and Goldsby (2009) developed a typology of the risks faced by a firm. These include both internal and external risks. One of the risk categories they propose encompasses external factors or “framework factors”, as defined by Ritchie and Marshall (1993). These factors describe the market environment in which the firm

operates. The factors include environmental risks, industry risks and organizational risks, (Rao and Goldsby, 2009).

Environmental risks include natural disaster risks, political risks, social risks and macroeconomic risks, (Rao and Goldsby, 2009). We understand that environmental risks can set up the structure of the market per SCP. This study focuses on geopolitical risk and natural disaster risk, and the impact that these risks have on firm performance. The first link we look at is a direct link between structure and performance. Holweg et al. (2011) state that political risk is a *hidden* cost for firms, since they make the decision to go into higher risk countries based on predicted operating costs, without considering political risk. They pose that the additional hidden costs may exceed the operating cost savings from operating in high risk countries, but in their case study there is no irrefutable statistical evidence to support this argument.

The tradeoff at hand is between the advantages that operating in a low cost country can bring and the hidden costs that political issues in that country can cause. Operational costs such as low labor costs, low inventory handling costs, low infrastructure costs and low cost of transportation are the main reasons why firms decide to invest in having a manufacturing presence at countries that are less politically stable, (Holweg et al., 2011). Ports and airports are critical points for any supply chain. If the country in which a firm is operating is impacted by a political crisis (a coup, an invasion, a dramatic change of government structure, etc) government owned agencies and processes will be affected as well along with the availability of employees to be to go to work, causing a disruption in the capacity to

produce and move goods through the supply chain. The latter are the risks that Holweg et al. (2011) argue that are not being considered and therefore become hidden costs. Although the literature (Christopher and Holweg, 2011; Holweg et al., 2011) portrays a negative impact from operating in risky places, suggesting that these risks should be avoided, we believe that the cost benefits are still higher than the impact of the hidden costs. Holweg et al. (2011) utilized three case studies to test the impact of risk on performance. We expect that looking at a greater sample, results will vary depending on the firm and the places that the firm is operating in. We think that the global environment of business and the turbulence that comes with it have become the normal way of doing business and to deliver a low cost product has become an entry barrier. In order to penetrate a market, it is necessary to have a product with a competitive price. To compete in a global market, economies of scale are necessary in order to deliver an attractive price. High risk countries can bring this benefit. We expect higher geopolitical risk to be associated with higher performance.

Natural disaster risk is slightly different from geopolitical risk. When it comes to hurricanes, for example, there is a hurricane season every year that goes roughly from June to November. Firms operating in places located in the hurricane zone, can expect to be impacted during that time of the year more than at any other time of the year. Earthquakes are completely different and much less predictable. However, natural disasters are disasters that do follow patterns. Even though it would be almost impossible to predict one precisely, it can be estimated statistically that certain places will be impacted in a certain time range. In “the next five or ten years”, depending on the historical statistical data. Insurance companies use this type of data to estimate the

probabilities of being affected and calculate insurance premiums (Sheffi 2005). Countries exposed to natural disasters are similar to countries with geopolitical risk in terms of low operational costs. They can provide the same advantages of low cost labor and low cost operations. They present an important difference from geopolitically unstable countries that it would be easier for firms to defend from the environment because statistical data is more reliable and the probability of an event does not depend on human action. These countries are also attractive for manufacturing due to the cost advantage they represent. For this reason we expect natural disaster risk to have a positive impact on performance.

Our first hypothesis is divided in two parts to consider both risk types individually because we are interested in understanding if the difference between the two risk types are enough to have a different impact on performance. Hypothesis one is as follows:

H1: *Higher location environmental risk will be positively associated with firm performance.*

H1a: *Higher geopolitical risk will be positively associated with firm performance.*

H1b: *Higher natural disaster risk will be positively associated with firm performance.*

ii. Supply Chain Complexity

Complexity in the supply chain is not only provided by the global environment, but also by the complexity of the products and the number of nodes in the network. Bode and Wagner (2015) explored three types of complexity in the

supply chain: horizontal (# of direct suppliers), vertical (# of tiers) and spatial (# of countries). They found that complexity increases disruption frequency, therefore impacting the performance of the supply chain network. Blackhurst, Dunn and Craighead (2011) studied complexity in terms of the size of the network given by the number of nodes and the connectivity between nodes. They find that complexity reduces resilience, making the firm more vulnerable to its environment. Although none of these two studies refers to product complexity, we understand the more components a product has, the more horizontal complexity the firm will have because it will require more suppliers. A product with a complex design could imply more stages of production which will also impact the number of tiers for its supply chain. In this study we will look at a combination of product complexity and network size complexity. We are not able to define complexity in the same ways Bode and Wagner (2015) and Craighead (2011) did due to data limitations, but product complexity combines both studies as it poses a risk for the supply chain to be bigger and more exposed to be disrupted. Following their findings, we expect product complexity to have a direct negative impact on performance. Complexity makes for a more difficult to manage environment, hence our second hypothesis is:

H2: *Supply chain product and network complexity will be negatively associated with firm performance*

iii. Disruptive Events

The last environmental factor we consider is the number of disruptive events that a firm experiences. Although the media has contributed immensely to raising awareness as to why it is important to mitigate supply chain risks, the media typically

fails to delve into the factors that would be helpful for researchers to better understand the risk management process. In terms of supply chain risks and disruptions, low probability, high impact disruptions tend to get most of the attention, while “everyday risks” that might be low to medium impact events do not get much notice.

Hendricks and Singhal (2003) have contributed to the literature by empirically establishing relationships between risks, disruptions and firm performance. Their research allows us to understand why the study of supply chain risk and supply chain risk management is not only interesting but also relevant and important. They have established that supply chain disruptions have a negative effect on stock performance (Hendricks and Singhal, 2003), that disruptions have a long-term effect on stock performance and equity risk (Hendricks and Singhal, 2005a), and that supply chain disruptions negatively impact operating performance, (Hendricks and Singhal, 2005b). They have also studied the impact of mitigation strategies, such as operational slack and diversification, on the disruption events (Hendricks et al., 2009). With their findings, the authors have established the importance of supply chain risk awareness and mitigation, and its main goal to protect the performance of the firm.

Sheffi (2005) presents a collection of case studies based on different disruptions that a diverse selection of firms have faced. The aftermath of these disruptions ranges from loss of sales in that year to (at the extreme) bankruptcy. Sheffi finds that there are identifiable warning signs before high impact disruptions

happen that a firm may have missed. Suggesting that it is possible to learn from lesser impact events and be better prepared or even avoid a bigger impact event.

Other studies have focused on identifying ways to predict the impact of disruptions or to calculate the probability of disruptions happening. Such studies use methods such as field experiments (Hora and Klassen, 2013), experiments (Tazelaar and Snijders, 2013) and simulation (Neiger, Rotaru and Churilov, 2009). Regardless of the methodology, the study findings show that disruptions have a negative impact on firm performance.

It is important to make a distinction between disruptions and disruptive events. A disruption is an event that temporally interrupts the normal flow of goods at one or more stages of the supply chain. Hendricks and Singhal (2003) use actual public announcements of business disruptions in their studies. These were identified by production delays or shipping delays. In our study we will look at disruptive events. For example, a flood in Thailand in 2014 closed over a thousand factories. A firm with manufacturing locations in Thailand might or might not be impacted by this event. Even more, a factory in the impacted region, could have been prepared and not have significant damage while another factory that was less lucky or less prepared was impacted more. A factory that did not get flooded, could still be impacted because of the difficulty to move goods that a flood poses. Disruptive events are events that a firm faces but may not actually interrupt the normal flow of goods of the firm's supply chain. This study looks at events like this one and assumes that if a firm had manufacturing locations in the area impacted by the event, then this firm had to face dealing with this event even if the event did not become a network disruption for

the firm directly impacting performance. We expect that the probability of having a disruption that affects performance increases the more disruptive events a firm faces. These events make the supply chain environment more hostile and they posit threats for the supply chain that can add up to a significant impact to performance. We posit that:

H3: *The higher the frequency of disruptive events a firm has to face the lower the performance of the firm will be.*

Conduct

Traditionally in the SCP framework, conduct refers to the responses that firms have to the competitive environment. In our case, we are looking at cultural traits that would make a firm stronger at reacting to risk, thus granting it competitive advantage. Supply Chain Risk and Supply Chain Risk Management are frequently studied together. The literature in Supply Chain Risk Management (SCRM) has identified four stages of SCRM: 1) identification (Neiger et al., 2009; Trkman and McCormack, 2009), 2) assessment (Ellis et al., 2010; Hendricks and Singhal, 2005), 3) mitigation (Jian et al., 2009; Knemeyer et al., 2009) and 4) responsiveness (Kleindorfer and Saad, 2005). Supply Chain Risk Management is defined by Manuj and Mentzer (2008) as:

“The identification and evaluation of risks and consequent losses in the global supply chain and implementation of appropriate strategies through a coordinated approach among supply chain members with the objective of reducing one or more of the following – losses, probability, speed of event, speed of losses, the time for detection of the events, frequency, or exposure –

for supply chain outcomes that, in turn, lead to close matching of actual cost savings and profitability with those desired.”

It is evident from this definition that SCRM involves anticipating and managing a potential or actual disruption, from before it happens until its effects are over. The SCRM literature has proposed many alternatives in which firms can cope with the risks in which they operate. Some examples of risk mitigation strategies include: supply chain agility (Braunscheidel and Suresh, 2009), flexibility (Seebacker and Winkler, 2013), redundancy (Carvalho et al., 2012; Sheffi, 2005), decision making process development (Manuj and Mentzer, 2008; Speier, Whipple, Closs and Douglass Voss, 2011), and proactive actions to identify and assess risks (Kleindorfer and Saad, 2005; Trkman and McCormack, 2009; Knemeyer et al, 2009).

Supply chain resilience encompasses all these aspects. It is often considered to be a response to the risky environment, and can be seen as complementary to supply chain risk management (Mandal, 2012). Sheffi (2005) posits that an effective risk management strategy can cultivate a culture of resilience. A firm that has learned to cope with the challenges of the environment, and has obtained competitive advantage from doing so, will be more capable to cope with new unforeseen challenges, such as unpredictable catastrophic events.

Sheffi (2005), in his book entitled, “The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage”, looks at different types of disruptions to the supply chain, and compares how companies impacted by the same disruption behaved before, during and after the disruption. He studies, for example, how a fire in a Philips plant in New Mexico in 2000 disrupted the supply chains of both Nokia and

Ericson. The significant difference in performance for these two firms after the disruption was due mostly to the way they managed the disruption from the time it took both firms to discover the disruption, to how they assessed the impact, managed their suppliers and customers and recovered from the inevitable loss, to the actions that were established afterwards to avoid a similar disruption in the future.

All of these factors point to a “way of doing things”, the organizational culture of the firm, that can facilitate the speed and efficient recovery from a disruption. In his conclusion, Sheffi points to an organizational culture of resilience as an asset for competitive advantage. This implies that a firm is able to utilize its processes, ways of communication, knowledge, employees and strategies to figure out how to deal with a situation that was not foreseen and had not happened before. The firm has a way to acquire new collective experience and knowledge and use it to perform better in the future. Sheffi claims that resilience can be an organizational cultural trait that can give firms competitive advantage.

Sheffi’s focus on culture is consistent with the Resource Based View (RBV) theory developed by Barney (1986). Barney’s RBV theory claims that the way in which a firm utilizes its resources can grant the firm sustainable competitive advantage. In order for a resource to bring competitive advantage, it has to be valuable, rare, inimitable and non-substitutable (VRIN). Barney (1986) specifically addresses the possibility for organizational culture to be a source of sustainable competitive advantage. He explains how some cultural traits bring economic value to a firm, and that these traits, if also rare and inimitable, can be the source of sustainable competitive advantage. Some examples of cultural traits with economic

value presented by Barney are: creativity and innovativeness, employee productivity and value of worth of employees, customer service and satisfaction. Our study aims to understand the link, if any, between supply chain resilience and firm performance. We look at resilience factors that constitute cultural traits and the impact of these factors on firm performance.

Organizational culture is a multilevel, complex concept. According to Schein, (1986) there are three levels of cultural phenomena in organizations: 1) behaviors and physical manifestations, 2) values and 3) basic assumptions. The basic assumptions are at the deepest level of the culture, and are the traits that are understood as “correct ways” to cope with the environment. This is the most difficult level to measure because it is the most taken-for-granted behavior of a culture. In a firm with supply chain resilience as part of its basic assumptions, it would be expected for manufacturing locations that face potential disruptions to have a business continuity plan in case a disruptive event happens. These basic assumptions have measurable expressions that we can observe and study.

Gordon (1991) explains how the environment in which a firm is operating, specifically the industry, determines the organizational culture that a firm develops to compete in its industry. He states that: “the competitive framework in which a company operates is an important dimension on which core assumptions in the company culture are developed.” In his conceptual model, he establishes that the industry environment (constituted by customer requirements, competitive environment and societal expectations) has an impact in the formation of assumptions and values for the organizational culture of the firm, and that these values are

translated into “forms” (constituted by strategies, structures and processes). These forms subsequently have an impact on firm performance. Following this reasoning, we argue that the current global market environment can trigger a culture of resilience that is translated into “forms” that are resilience strategies. For example keeping more inventory than necessary in certain locations so that order fulfillment can be continued when a location is impacted by a disruptive event.

We build on Gordon (1991) model, expanding the industry environment to the global market environment. Our assumption is that the organizational cultural forms of resilience can be captured in business practices, and these can be used to assess their impact on firm performance. The assumptions and values of the culture remain unmeasurable, and can be considered as inimitable and rare.

Kamalahmadi and Parast (2016), in their literature review of Supply Chain Resilience, defined resilience as:

“The adaptive capability of a supply chain to reduce the probability of facing sudden disturbances, resist the spread of disturbances by maintaining control over structures and functions, and recover and respond by immediate and effective reactive plans to transcend the disturbance and restore the supply chain to a robust state of operations.”

Christopher and Peck (2004) identified principles of supply chain resilience. The main four principles are reengineering, collaboration, agility and a culture of SCRM. Combining the contributions of Christopher and Peck (2004) with the definition of Kalahmadi and Parast (2016), we can say that a culture of SCRM can be identified with the anticipation phase of Kahlmadi and Parast (2016) definition, re-

engineering is identified with the resistance phase and agility is identified with the recovery phase. In our theoretical frame, the structure of the environment presents risks that in order to develop and maintain competitive advantage, firms develop an organizational culture of resilience that allows them to utilize and reorganize resources to better serve the needs of the firm according to RBV and enhance performance. Consistent with the supply chain resilience literature, RBV and organizational culture theory, we propose our fourth hypothesis as the positive impact of resilience on firm performance. This hypothesis establishes a link between conduct and performance.

H4: *Supply chain resilience will be positively associated with firm performance*

Since resilience is an organizational cultural trait, we divide H4 into three parts, for three different indicators of resilience: financial resilience, redundancy in the form of inventory and anticipation and recovery in the form of estimated recovery time.

Fiksel et al. (2015) state that financial strength is a resilience factor. A firm must be able to absorb fluctuations in cash flow in order to be resilient to disruptions. Kamalahmadi and Parast (2016) establish that it is necessary to “recover and respond by immediate and effective reactive plans to transcend the disturbance and restore the supply chain to a robust state of operations.” For a firm to be able to accomplish this, it must have the resources available to absorb the immediate cost that going back to a robust state of operations will require when the firm is impacted by a disruptive event.

Our assumption is that a firm that is financially solid, would know what kind of financial measure to take in specific circumstances (insurance against certain type of events, inventory investments, multiple production facilities, etc.). Sheffi (2005) gives the example of using insurance when exposed to natural disasters. He says that since there are historical statistical data available, insurance companies are able to develop reliable statistical predictions, and insurance can be one of the measures to build resilience. Such a firm, would know not only how and when to protect from potential disruptions but how to invest money in general to increase performance. The first indicator of resilience that we look at is the financial solidity of the firm that we are calling financial resilience.

H4a: ***Financial resilience** (financial solidity) will be positively associated with firm performance.*

Redundancy and slack have been identified with resilience by multiple studies (Hendricks and Singhal, 2009; Blackhurst et al., 2011; Fiksel et al., 2015; Kamalahmadi and Parast, 2016). Redundancy is one of the key indicators of re-engineering (Kalahmadi and Parast, 2016). It allows a firm to rearrange its resources to ensure a faster recovery from a disruption while order fulfillment is not interrupted.

During the 1980's and 1990's, keeping a lean inventory strategy was the main trend in many industries. Firms invested in lean manufacturing implementations involving inventory analysis, process revisions and design and employee training to use new analytical tools. Some firms even combined a lean manufacturing culture with a six sigma analytical approach to lean processes in order to improve firm performance. However, enormous global disruptions, such as the Japan tsunami in

2011, put the lean culture to the test. The interruptions in business were especially telling for Toyota, in particular, since Toyota is the firm where lean manufacturing originated.

Empirical evidence on inventory shows that total inventory did indeed decrease for US manufacturing firms from 1961 to 1994 (Rajagopalan and Malhotra, 2001). When accounting for the trends in the three types of inventory, raw materials, work in progress and finished goods, the study finds that finished goods inventory did not decrease as steadily as the others. The results for finished goods varied by industry and did not significantly change during the period for more than half of the industries in the study. These findings are not completely supportive of the lean inventory push.

Chen et al (2005) examined inventory trends from 1981 to 2000. They found that inventory decreased at a rate of 2% per year; but again, finished goods inventory did not change. They found that firms with abnormally high inventory perform poorly, while firms with slightly lower than average inventory had good returns. They found no evidence for extremely lean inventory providing the best performance. Moreover, the lowest level inventory firms performed at about average levels. Therefore, empirical research does not provide strong evidence in favor of lean inventory policies contributing to better performance. It does seem to provide evidence for a “reasonable leanness”; that is, keeping inventory close to the industry mean seems to pay off.

The supply chain risk management and resilience literature suggests that inventory levels should be kept at some level above the lowest necessary level in

order to reduce the potential impact of unforeseen events. Empirical findings show that inventory can effectively mitigate the impact of a disruption on performance. Hendricks et al (2009) found that inventory slack mitigates the negative effect of a disruption on stock value, using actual disruptions announcements and publicly available data. Schmitt and Singh (2012) found through a simulation study involving a multi-echelon supply chain that inventory placement can have unforeseen benefits in the recovery from a disruption. Liu, et al. (2016) present an analytical model that allows a firm to perform a virtual stockpile of inventory to increase resilience and avoid excess inventory. The model operates at a network level by targeting a virtual transshipment effect that proves to be more cost efficient than simply keeping safety stock at a node level.

While inventory buffers or safety stock have often been considered to be part of a supply chain resilience construct (Mandal, 2012; Blackhurst et al., 2011; Ambulkar et al., 2015; Carvalho et al., 2012; Park et al., 2016), high levels of inventory have been found to be detrimental to firm performance, and are associated with inefficiencies. High inventory levels have been associated with lower product quality and more product recalls (Steven and Britto, 2016) and lower sales (Ton and Raman, 2010). As a result, there are contradictory findings on the benefits of holding inventory in the different streams of literature.

The findings of Chen et al. (2005) provide a path to better understanding this contradiction. Their empirical findings indicate that staying close to the industry mean on days-of-inventory delivers, on average the best operating performance. Firms that operated at slightly below the mean and slightly above the mean inventory

levels performed better than very lean firms and firms with much greater than average inventories. Based on this finding and the findings on redundancy from the supply chain resilience literature, we would expect that above the industry mean would be where a resilient firm will keep their inventory level. We pose the following hypothesis:

H4b: *Higher **inventory** will be positively associated with firm performance*

Knemeyer et al. (2009) proposes proactive planning and the creation of contingency plans as a risk mitigation strategy. Kamalahmadi and Parast (2016) identify proactive planning as the first stage of resilience and Blackhurst, Dunn and Craighead (2011) find contingency planning to be a resilience enhancer. Therefore, we expect that firms that identify potential disruptions and calculate recovery time scenarios, will be better performing firms because they have embedded resilience as a part of their organizational culture. Hence:

H4c: ***Recovery resilience** will be positively associated with firm performance*

Performance

In the Supply Chain Resilience literature, resilience has been used as both an independent and dependent variable. Studies have examined the impact of resilience measures on costs (Liu, Song and Tong, 2016), disruption impact and depth (Ambulkar, Blackhurst and Grawe, 2015; Kim, Chen and Linderman, 2015; Carvalho, Barroso, Machado, Azevedo, Cruz-Machado, 2012) Other studies have focused on how to build resilience, studying antecedents, strategies, enhancers and

reducers of resilience (Christopher and Peck, 2004; Soni, Jain and Kumar, 2014; Blackhurst, Dunn and Craighead, 2011).

While looking at the impact of disruptions, Hendricks and Singhal (2003) empirically test the impact of disruptions on firm performance using stock value, inventory costs, operational costs and long term stock value as a performance measures. They also test the mitigation impact of operational slack that sheds light on the impact of resilience.

There is no study in the literature that empirically tests the impact of risk and resilience using a performance variable that encompasses both costs and revenue. In this study we are interested in the net effects of our variables on firm performance; for this purpose we chose gross margin as the performance measure. Gross margin measures the percentage of each dollar of revenue that the firm keeps after considering the costs of goods. It is a good measure for the understanding of the impact of risks and resilience on firm performance.

To summarize, Figure 1 shows Gordon’s model published in the Academy of Management Review on the top (Gordon, 1991) and a conceptual model of our hypotheses on the bottom.

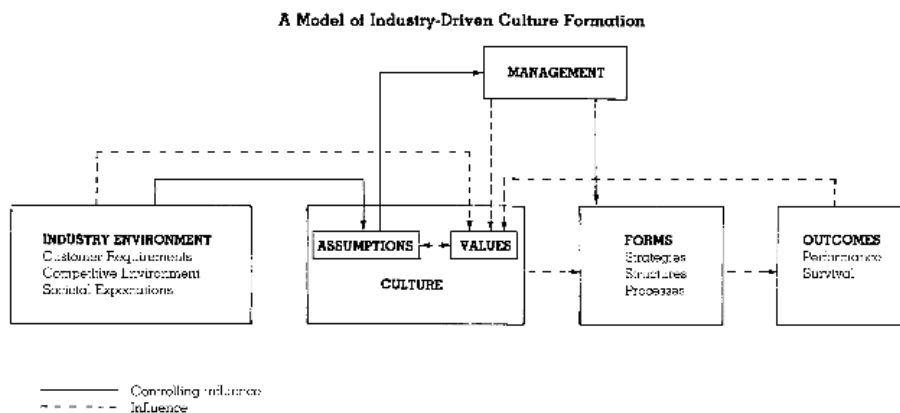
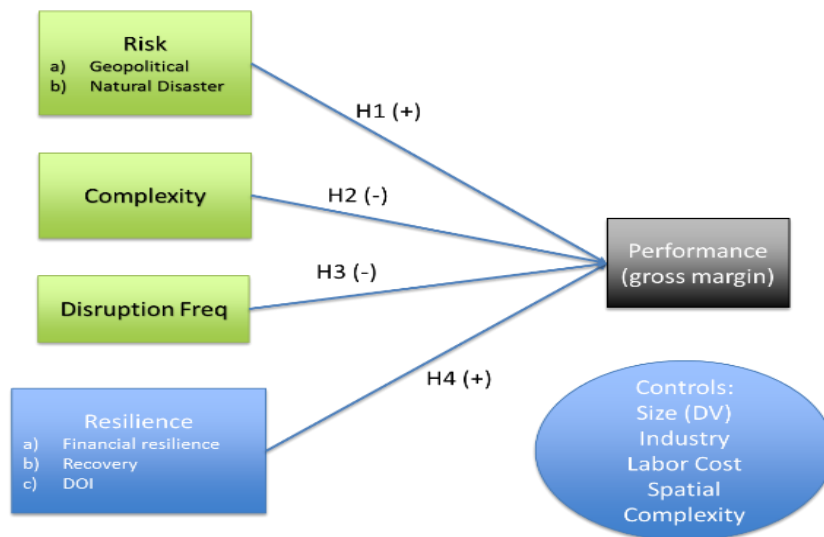


Figure 1:
Gordon’s Model
and Hypotheses
Model



METHODOLOGY

a. Data

In this study we combine data from 3 data sources.

i. Resilinc Data

Our first data source is from the firm, Resilinc. Resilinc provides supply chain risk management services to its clients. The Resilinc software tool allows firms to

track their supply chains, as well as their supplier's supply chains, identify vulnerabilities in the supply chains, design resilient strategies, take mitigating actions to reduce vulnerabilities, and receive notification of disruptions using social networks, among other services. A Resilinc customer can use the software to map its internal supply chain and the supply chain of its suppliers, linking bills of materials to component suppliers and the manufacturing locations where these components are processed.

Resilinc keeps track of news through social media notification, and provides announcements of potential disruptive events affecting a geographical area. Since the locations of a firm are mapped using the Resilinc software tool, the program forwards notifications with impact estimations to firm executives according to a notification hierarchy established by the firm that is also part of the tool. A customer is able to identify vulnerabilities across supply chain tiers, and identify if the firm will be impacted by a disruptive event and the potential extent of the impact. The customer can also assess the potential risk of its suppliers, its products or the geographical regions in which it holds operations.

Resilinc provided us the population of disruption alerts that were sent during the year, 2014. These events are categorized into 4 types: 1) hurricanes, 2) fires, 3) earthquakes and 4) other. When a potential disruption is identified, Resilinc sends a notification customized for each firm with relevant details such as, the number of sites impacted and the potential revenue impact. The customer has the advantage of immediate notification, and managers can begin to make plans and decisions

providing the firm visibility into the disruption and the opportunity to recover from the disruption.

For the purposes of identification, the Resilinc customers are referred to as the “focal firms”. These are the firms that are making investments in developing resilience for their supply chains. For this study, we were also provided with data from focal firms’ suppliers for the year, 2014. Our dataset, therefore, is a cross section for the year, 2014 consisting of data related to the supply chains of Resilinc customers. The database contains information on both tier 1 and tier 2 suppliers to the focal firms.

The Resilinc service includes identifying “critical” production sites for the focal firms. This criticality is most often given by the fact that in those sites critical activities that affect high revenue products are performed. Therefore, an interruption to these sites could have high revenue impact. For example, these sites are often places where single-source activities are taking place. Since these places are linked to high revenue impacts, the risk assessment exercise includes business continuity plan and recovery time calculations.

The dataset often contains information on multiple manufacturing locations per supplier firm. This information includes: 1) site geographical location (country and coordinates), 2) site risk scores (based on country risk scores provided by the Economist Intelligence Unit), 3) recovery time (self-reported analysis of disaster recovery given in weeks), 4) critical parts that are handled at that location and 5) actual potential disruptive events in the year 2014 that affected the geographical area where the facility is located.

We gathered a sample of firms from the Resilinc database that contains all the publicly traded firms and their manufacturing locations. We then matched these firms to firms in the Compustat database in order to get financial information on the firms. A total of 313 firms matched with Compustat. These are linked to 3,262 manufacturing locations, 75 countries, and 40 industries following a three-digit NAICS code.

Even though the risk scores for each manufacturing location were provided by Resilinc, it is important to note that the geopolitical risk scores originated at the Economist Intelligence Unit (EUI). The EUI provides many services of risk assessment using scores from 1 (lowest risk) to 10 (highest risk). In our study, we use three of these scores to assess the geographical risk associated with a location: Geopolitical Risk, Natural Disaster Risk and Macroeconomic Risk. These are revised and updated every three to five years by the EUI, depending on the score and the country assessed.

ii. Compustat

In order to evaluate the effects of risk and resilience on firm performance, we use Compustat to obtain data on publicly traded firms. We use the year 2014 to calculate the gross margin, days of inventory and the Altman Zscore (a measure of financial risk). We use only publicly traded firms from the Resilinc dataset to match with the Compustat data set. The end result is a dataset that contains 313 firm level observations.

For the long-term variables, we use 3, 5 and 10 year Compustat industry aggregated data. Using a 3-digit NAICS code, we calculate the mean and standard deviation of the industry for inventory days of supply and gross margin.

iii. International Labour Organization (ILO)

Typically firms choose higher risk environments in order to benefit from lower costs of labor. Therefore, to complete our data sample, we use a measure for labor costs. The International Labour Organization provides data on minimum wages for countries. The minimum wage data is provided as a monthly wage according to the most recent laws in the various countries. For this study we use the year of 2012 and convert all the values to US dollars to allow comparability of costs. The year 2012 was the most recent year available for data provided by the ILO before 2014.

iv. Final Database

We started with over 1,000 firms and 25,000 manufacturing locations provided by Resilinc. 325 of the firms were publicly traded, with financial information reported in Compustat. 12 firms were eliminated. 4 were duplicates were found and deleted and 8 were name mismatches. 313 publicly traded firms were left. There are 3,262 sites attached to these firms. Therefore, the 2014 cross sectional sample contains 313 firm level observations.

The data that were originally provided at the manufacturing location level are aggregated to create firm level variables. Geopolitical risk, natural disaster risk, minimum wage and recovery time are aggregated to the firm level. The total number of countries in which sites are located for a firm is a count variable at the firm level. The number of critical parts that are managed at a location and the events that

impacted each site are also aggregated as a count variable to the firm level. Days of inventory, gross margin and the financial resilience variable based on the Altman z score are calculated at the firm level using Compustat data. Finally the long term variables for days of inventory and gross margin are also calculated at the firm level.

Hence, the 2014 cross sectional database has 313 firm level observations that include: 1) average geopolitical risk, 2) average natural disaster risk, 3) average minimum wage, 4) average recovery time, 5) number of countries, 6) number of parts, 7) number of events, 8) days of inventory, 9) financial resilience, 10) standard deviations from industry mean days of supply over 3, 5 and 10 years; as independent variables and gross margin and standard deviations from industry mean gross margin over 3,5 and 10 years as dependent variables. This database is divided into sub-sets for the purpose of analysis. Details about these groups are discussed with the models.

v. Missing values

Some firms failed to provide their recovery time and the number of critical parts managed in the site. In order to address these omissions, we use a standard procedure for estimating missing values and input the mean value for each of the above mentioned firms (Rencher, 2002).

b. Variables

i. Environmental Risks

The environmental risks variables are chosen following the typology established by Rao and Goldsby (2009). Environmental risks are external to the firm and are related to the firm's geographical environment. Out of the possibilities listed in their study, we include two environmental risk measurements:

1. Natural Disaster Risk

The natural disaster risk score ranges from 1 to 10 and measures the probability of the geographical region where the manufacturing location is situated being hit by a natural disaster (hurricane, tsunami, earthquake, tornado, etc). 10 represents the highest probability of an event and 1 represents the lowest. This score is developed using Resilinc proprietary algorithms and may differ marginally from other published scores since it takes into account different regions within a big country such as the United States. A natural disaster can temporarily block the capacity to move goods into and out of the country, as well as restrict the capacity to produce due to the country's crisis. This measure is aggregated to the firm level by calculating an average between all the sites belonging to the firm. We refer to this variable in short form as "Natural".

2. Geopolitical Risk

The geopolitical risk scores range from 1 to 10 and measure the political stability of the country where the manufacturing sites are located. 10 represents a highly unstable country and 1 represents a very stable country. This score is developed and published by the Economist Intelligence Unit using proprietary algorithms to determine the probability of a country going through an invasion, a change of government, a coup, or experiencing some other kind of political instability. Political instability can impact the supply chain by blocking the normal flow of goods in the country. Government managed critical points, such as ports and borders, might not function properly under a political crisis, for example. This

measure is assessed at the firm level by calculating an average between all the sites belonging to the firm. We refer to this variable in short term as “Geo”.

ii. Complexity

We follow the definition of complexity that refers to the size of the network and the connectivity between the nodes as per Blackhurst, Dunn and Craighead (2011). For each manufacturing site in the Resilinc database, the number of critical parts managed for a manufacturing process are indicated. This variable provides a count of how many critical parts are processed at the location. The location counts are aggregated to the firm level by adding the total critical parts that are managed at all sites for the firm. Note that this is not the measure of a firm’s total number of critical parts, nor is it a measure of how many nodes there are in the network. It is a measure of how many times a critical part must be managed at a location. This variable provides an approximation of the complexity of a supply chain. In some cases, there may be multiple nodes for a particular critical part.

iii. Disruptive Events

In 2014 there over 90 disruptive events tracked by the Resilinc program. These events are grouped into 4 categories: Hurricanes, Fires, Earthquakes and Other. These events were provided in the data base with the geographical region that was impacted. The geographical coordinates of the regions allowed us to link manufacturing locations to events.

Our variable Events, measures how many times a site is impacted by an event. This quantity is measured at the firm level by adding all the events of all the sites for a firm. This variable provides an estimate of how many times the firm had potential

disruptions in 2014. Note that this is not a measure of the impact that the events had on the firm, as it is possible that the site managed the event without interruption. With the frequency of disruptive events, we are measuring events that the firm faced, not the impact of the events on firm performance. This variable, therefore, is different from the disruptions variable used by Hendricks and Singhal (2003) that measured the impact of publicly announced disruptions.

iv. Resilience

Following the definition of resilience from Kamalahmadi and Parast (2016), we establish three measures of resilience for each firm:

1. Financial Resilience

Financial resilience is a score from 1 to 10 based on the Altman Z-score. The z-score measures how likely it is for a firm to go bankrupt in the next two years. It can be used to assess the financial health of a firm. We introduce this score to the supply chain resilience literature as a measure of financial solidity. Following Fiksel et al, (2015), a financially solid firm would more likely be able to recover and bounce back from a disruption than a financially unstable firm. The score is normalized to a 1 to 10 measure. 10 represents the most financially solid firm and 1 represents the weakest firm. We refer to this variable in short form as “finres”.

2. Inventory

We use days of inventory as a measure of inventory. Days of inventory standardizes the amount of inventory that the firm keeps regardless of firm size or industry. This variable is calculated using the following formula: $(1/\text{inventory})$

turns)*365, where inventory turns is calculated as: $\text{Cost of Goods Sold} / ((\text{Beginning Inventory} + \text{Ending Inventory}) / 2)$. We refer to this variable in short form as “DOI”.

3. Recovery Resilience

Recovery Resilience is adjusted to range from -10 to -1. Each site in the Resilinc database may report the time it would take to return to operations after the site has been shut down due to a disruption. Therefore, the variable does not measure actual recovery time, but projected recovery time following a disaster. An analysis of the impact of a disaster is conducted at a site, and an estimate of how long it would to return to regular operations is calculated. This time was reported originally in weeks and converted into a score from 1 to 10. The sign is inverted such that the higher the recovery resilience, the faster the site will recover. This adjustment is made to aid in interpreting the regression models. The fastest recovery is represented by -1 and slowest recovery is represented by -10. Then the site measures are assessed at the firm level by averaging the recovery resilience scores of all the sites belonging to a firm. We refer to this variable in short form as “RecRes”.

v. Performance

The dependent variable for this study is gross margin, a measure of firm performance. Gross margin allows us to understand how much per dollar of revenue a firm retains after the costs of production. Gross margin is calculated by subtracting the cost of goods sold from the total revenue and dividing it by total revenue. We use the short form “gmargin” for this variable.

The dependent variable for the long term effects models is also based on gross margin. However, the variable measures the number of standard deviations above or

below the industry mean gross margin. To calculate this variable the mean gross margins over 3, 5 and 10 years of the 3 digit NAICS code industry were calculated, along with corresponding standard deviations. The firm's average gross margin over those years was calculated as well. Then the following calculation is used: $(\text{firm average gross margin} - \text{industry mean gross margin}) / \text{industry gross margin standard deviation}$. We call these variables *gmarginsd3*, *gmarginsd5* and *gmarginsd10*.

vi. Controls

Since the cost of labor is a major reason for operating in a country, we control for labor cost. We use the minimum wage reported for the country in which the site is located by the International Labor Organization for 2012. This amount is converted to dollars. This measure is assessed by an average at the firm level. We use the short name "mwage" for this variable.

We have established through the literature that globalization has an impact on firm operations and that this can impact the firm's performance. We control for spatial complexity per Bode and Wagner (2015) as the number of countries in which a firm operates.

Finally, we control for industry effects through the model. The model adjusts the standard errors by clustering the firms by industry. We control for firm size by choosing the dependent variable to be a ratio, instead of Total Revenue or some other size-specific measure of firm performance.

Table 1 shows a summary of variable descriptions and data sources.

Variable Name	Source	Description
Geopolitical Risk	EIU	the degree to which political institutions are sufficiently stable to support the needs of businesses and investors
Natural Disaster Risk	Resilinc	Probability of a natural disaster occurring in the region.
Recovery Resilience	Resilinc	How long it takes to go back to “normal” on an activity that has been disrupted. Calculated: (-10*recovery time/52)
Min Wage	ILO	Min monthly wage for the country. (2012 USD)
Countries	Resilinc	Number of countries the firm has operations in
Critical Parts	Resilinc	Number of critical parts the firm is monitoring
Financial Resilience	Compustat	Altman Z score, measure of likelihood that the firm will go bankrupt in the next 2 years. Calculated
Events	Resilinc	Number of potential disruptions a firm had in 2014
DOI	Compustat	Days of Inventory. (1/inv turns)*365
Gross Margin	Compustat	(Total Revenue – COGS)/Total Revenue
DOI SDS	Compustat	Number of standard deviations firm mean is below industry mean (Neg. No.) or above industry mean (Pos. No.)
Gross Margin SDS	Compustat	Number of standard deviations firm mean is below industry mean (Neg. No.) or above industry mean (Pos. No.)

Table 1: Variables and Data Sources

Models

In order to test our hypotheses we use a linear regression model with industry clusters. The general equation for all our models is:

$$\begin{aligned}
 grossmargin = & \alpha_1*(natural\ disaster) + \alpha_2*(geopolitical) + \alpha_3*(CritParts) + \\
 & \alpha_4*(Events) + \alpha_5*(finresilience) + \alpha_6*(DOI) + \alpha_7*(resilience) + \\
 & (controls) \dots\dots\dots (Equation 1)
 \end{aligned}$$

We estimate a robust clustered model using the Stata software package. This model controls for industry effects by adjusting the standard errors by industry clusters.

- i. Short Term Models (1,2,3)

The final database contains 313 firm level observations. Out of these 313, 156 contain data for the recovery time and 157 do not. The same 156 firms with recovery time data also have data on critical parts.

In order to obtain robust results, we divide the database into three groups. The first group is named ALL and it contains all 313 firms. For the firms that are missing the recovery time and critical parts data, the mean values are assigned. Group 1 is constituted by the firms that do have recovery time and critical parts information, in other words, the firms with a resilience culture. Group 2 is constituted by the firms that do not have this information, in other words the firms without a culture of resilience. In this way, we can compare the results from all three groups. Model 1 is the regression ran with the group named All that contains all 313 firms. Model 2 corresponds to Group1 and Model 3 corresponds to Group 2. These three models use the cross-sectional data for 2014.

ii. Long Term Models (4,5,6)

Shein (1985), Barney (1986) and Gordon (1991) state that it is difficult to change culture because the deepest level of assumptions generate behaviors that are “automatic”, making them difficult to recognize and change. They all agree that if it is possible to change culture, it takes a long time. Working on this assumption, we would test our resilience variables over time.

Model 4 corresponds to the group All, using the 10-year standard deviations from the industry mean gross margin variable as a dependent variable. Model 5 and Model 6 correspond to the 10-year models for Group 1 and Group 2 respectively.

RESULTS

Table 2 shows the descriptive statistics for all variables for the three groups in the models: the total sample, the group that provided recovery estimates and that group that did not. Note that this table suggests that Group 1 and Group 2 might be different. Table 3 shows the correlation table for all variables in the main database.

Table 2: Descriptive Statistics

Variable	All					Group 1					Group 2				
	Obs	Mean	Std.	Min	Max	Obs	Mean	Std.	Min	Max	Obs	Mean	Std.	Min	Max
Countries	313	4	4.820	1	42.000	156	6	5.639	1	42	157	3	3.253	1	22
Sites	313	24	165.863	1	2,922.000	156	42	233.758	1	2,922	157	6	9.637	1	78
CritParts	313	209	1039.636	0	14,153.000	156	419	1,444.626	0	14,153					
Geo	313	3.005	1.077	1	6.5	156	3.248	0.958	1.667	6	157	2.764	1.136	1	6.5
Natural	313	3.709	1.490	1	9	156	4.140	1.384	1	9	157	3.281	1.472	1	9
finres	229	0.741	1.992	-9.563	10	122	0.807	2.513	-9.563	10	107	0.666	1.146	-4.197	5.167
DOI	301	92.146	70.765	0.652	567.778	154	84.261	54.355	0.652	398.897	147	100.406	84.021	1.692	567.778
mwage	306	927.149	332.343	42.557	1,565.885	156	849.413	302.673	177.625	1,565.885	150	1007.995	343.346	42.557	1,565.885
events	313	10	16.154	0	109	156	16	20.304	0	109	157	4	6.694	0	42
RecRes	156	-6.960	3.212	-10	-0.192308	156	-6.960	3.212	-10	-0.192					
DOIstds10	262	-0.275	0.565	-1.143	2.996	142	-0.350	0.445	-1.143	1.591	120	-0.186	0.672	-1.066	2.996
gmargin	308	0.371	0.194	0.007	0.937	155	0.386	0.191	0.032	0.814	153	0.356	0.198	0.007	0.937
gmarginsds10	262	-0.026	0.873	-5.230	2.907	142	0.057	0.880	-1.870	2.907	120	-0.125	0.858	-5.230	1.522

Table 3: Correlations table

	Countries	TotalParts	Geo	Natural	finres	DOI	mwage	events	RecRes1	DOIstds	gmargin
Countries	1										
CritParts	0.32	1									
Geo	0.17	0.14	1								
Natural	0.03	0.08	0.57	1							
finres	-0.05	0.07	-0.10	-0.06	1						
DOI	0.02	0.16	0.09	0.16	0.25	1					
mwage	-0.14	-0.15	-0.87	-0.79	0.06	-0.07	1				
events	0.72	0.19	0.25	0.30	-0.09	0.15	-0.27	1			
RecRes1	-0.15	0.04	-0.06	-0.20	-0.02	0.02	0.10	-0.12	1		
DOIstds	-0.03	0.09	-0.02	0.16	0.20	0.82	-0.04	0.12	0.02	1	
gmargin	-0.09	-0.15	0.01	0.29	0.30	0.49	-0.10	0.19	-0.02	0.44	1
gmarginsds10	-0.15	-0.20	-0.13	0.13	0.32	0.34	0.03	0.09	0.04	0.51	0.83

Note that there are high correlation between some of the independent variables. Events has a 0.72 correlation coefficient with Countries. This is to be expected since the higher the number of countries, the higher the events frequency. The Natural Disaster risk and the Geopolitical risk also have a high correlation with a coefficient of 0.57. We decided to keep both variables in all our models because these two risk scores provide different information that is relevant to our study.

i. Difference of means test

Before testing the hypotheses, we ran a difference of means test for all the variables in Group 1 and Group 2. First, we want to understand if these groups are statistically different. Table 4 summarizes the results for the means tests. As can be seen in the table, these two groups are statistically different in the environmental risk variables. Group 1 has a higher mean for both Natural Disaster risk and Geopolitical Risk than Group 2. In addition, the firms in Group 1 have operations in more countries and experience more disruptive events, on average. This result suggests that the firms in Group 1 operate in a riskier environment or have a higher propensity towards risk. These firms seem to be risk seekers.

Interestingly, there is no statistical difference between the two groups when it comes to size (employees), revenue, gross margin in the year 2014 and financial resilience indicating that the firms are not differentiated by financial success or size. However, the firms in Group 1 seem to keep lower inventory levels than the firms in Group 2 at a 5% significance level. The firms in Group 1 practice more resilient

processes than the firms in Group 2. Recall we divided the sample using the recovery process and the critical parts tracking process as a differentiator.

The only variable that is significant with a higher mean for Group 2, is inventory. This result could suggest that the firms in Group 2 cope with their risks by keeping higher levels of inventory. It could also be evidence of a combination of lean and resilience, as suggested by Harrington (2013). She revisits lean culture and suggests that it should be combined with a culture of resilience to maximize performance. Lastly, the measure for the distance of gross margin from the industry mean over ten years, is significantly higher at the 5% level for Group 1 suggesting that resilience might in fact be the source of a sustainable competitive advantage.

Table 4: Difference of Means Tests Summary

	Group 1	Group 2			
	Mean	Mean	G1>G2	G1 ≠ G2	G1<G2
Geo	3.25	2.76	***	***	
Natural	4.14	3.28	***	***	
finres	N/A	N/A	N/A	N/A	N/A
DOI	84.26	100.41		**	**
events	15.85	4.25	***	***	
Countries	5.80	2.88	***	***	
gmargin	N/A	N/A	N/A	N/A	N/A
gmarginsds10	0.06	-0.13	**	*	
Revenue	N/A	N/A	N/A	N/A	N/A
Employees	N/A	N/A	N/A	N/A	N/A

Significance levels: *** .01, ** .05, * .1

ii. Regression Results for Short Term Models (1,2,3)

Table 5 shows the regression results for all six models. Geopolitical risk is not significant in any of the models, while natural disaster risk is only marginally significant in Model 1 but strongly significant in Model 2 with the expected sign, and not significant at all for Model 3. Therefore, we find partial support for H1. The complexity (critical parts) results for Models 1 and 2 are strongly significant with a negative sign for both models. Model 3 has no information on this variable. This result is consistent with findings in the literature. The surprising result is for disruptive events frequency. It is strongly significant but with the opposite sign from what was expected for Models 1 and 2 and not significant for Model 3. This result is contrary to expectations. We had hypothesized in H3 that more events would contribute to lower performance, however find contrary results. This finding may indicate that firms that more frequently face disruptions have learned how to manage these disruptions such that they do not impact performance. The fact that the sign is positive, indicates that for the firms in Group 1 there may be an argument for a resilient culture, since the results indicate that more events lead to higher gross margin. This finding is consistent with Sheffi (2005) and Fiksel (2015) who suggest that much can be learned about resilience from firms that operate in highly disruptive industries, such as fashion and technology.

For H4, the expected positive sign for financial resilience lends strong support in all three models for our hypotheses. The days of inventory results follow the same structure as the financial resilience results providing strong support for H4a and H4b.

In order to obtain a general understanding of the effect of recovery resilience, Model 1 contains all the firms. The recovery resilience variables for the firms in Group 2 are assigned average values. We see that the coefficient for resilience is marginally significant at the 10% level, with the expected positive sign. The results for Model 2 are stronger, with a significance level of 5%, indicating that for the firms in Group 1 faster recovery is associated with higher gross margins. It is interesting to note that this is a theoretical recovery variable; that is, the time that firms have calculated to recover from a disruption at a location.

Table 5: Regression Results

DV = Gross Margin	DV = Gross Margin SDS (10 years)					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	ALL	Group 1	Group 2	ALL	Group 1	Group 2
CritParts	-0.000026 ***	-0.000026 ***		-0.000140 ***	-0.000136 ***	
Geo	-0.0199	-0.0320	0.0129	-0.1592	-0.1889	-0.0576
Natural	0.0295 *	0.0495 ***	0.0124	0.0822	0.0909	-0.0034
finres	0.0224 ***	0.0193 ***	0.0251 ***	0.1210 ***	0.1113 ***	0.0432
DOI/DOIsds	0.0014 ***	0.0017 ***	0.0011 ***	0.4829 ***	0.8699 ***	0.3019 **
RecRes	0.0022 *	0.0031 **		0.0214 **	0.0171 **	
events	0.0036 ***	0.0030 ***	0.0047	0.0140 ***	0.0120 ***	0.0193
mwage	-0.000019	0.000021	0.0000	-0.000375	-0.000145	-0.000424
Countries	-0.0074 **	-0.0068 ***	-0.0072	-0.0290	-0.0315 **	-0.0260
cons	0.2363	0.1533	0.1150	0.7561	0.8534	0.4936
N	214	122	96	203	117	86
R²	0.3604	0.4736	0.2424	0.2362	0.4334	0.058
industries	28	17	23	14	12	13

Significance levels: *** .01, ** .05, * .1

iii. Regression Results for Long Term Models (4,5,6)

Table 5 also shows the results for Models 4, 5 and 6. In the long term effects we can see that complexity remains consistently significant with a negative sign, while none of the risk variables is significant. Financial resilience is significant for

models 4 and 5 but not for model 6. Days of inventory is consistent for the 6 models. It is in fact the only key variable with significance in Model 6, with a positive sign and a 5% significance level. Therefore, for Group 2, the only variable that has some explanatory power is DOI. Long term recovery resilience is also consistent with the short term results.

iv. Model 7: Events

Based on the results from Models 1 through 6, we added another model. The events reported in the database are categorized as 1) hurricanes, 2) fires, 3) earthquakes and 4) other. In an attempt to better understand the positive sign obtained for H3, we ran the model again. However, instead of using a total events count, we used a count for all 4 categories.

The results for this model show that Hurricanes has a positive and significant coefficient while Other has a negative and significant (10%) coefficient. The results for fires and earthquakes are not significant. We believe that this is because there are not enough events in these two groups. There are 67 total events out of which 21 are hurricanes and 32 are “Other”, with 5 fires and 9 earthquakes. The events in the Other category may be more unpredictable. Some examples of these are: “European financial crisis”, “Flooding in Thailand shuts down over 1,000 factories”, “Winter storm “Nemo” potential impact projection” and “Escalating conflict in Israel”.

On the other hand, hurricanes are fairly predictable events. Countries in the hurricane zone have been coping with hurricanes for years. The hurricane season covers the same months every year. Therefore, out of all the types of disruptions a firm might face, it could be argued that firms can learn to prepare for hurricanes and

develop a resilient culture around them. This is consistent with Sheffi (2005) who stated that statistical data for some natural disasters can be precise, and that insurance companies have developed very accurate prediction models for these events. Results for model 7 are shown in Table 6.

Table 6: Additional Model with Categories of Events

Model 7	
ALL	
CritParts	-0.00002 ***
Geo	-0.0259
Natural	0.0103
finres	0.0213 ***
DOI/DOIsds	0.0014 ***
RecRes	0.0041 *
Hurricane	0.0057 ***
EQ	0.0042
Other	-0.0034 *
Fire	-0.0151
mwage	-0.0001
Countries	0.0010
_cons	0.3499
N	217
R²	0.3920
industries	28

Significance levels: *** .01, ** .05, * .1

DISCUSSION AND CONCLUSIONS

The results provide empirical evidence that resilience has a positive impact on performance. The results also provide more interesting insight, that not all resilience strategies are equal.

Group 1 has a higher risk environment in terms of geographical risk, network size, complexity and global reach. For these firms, it is significant to have resilience strategies put in place. Financial solidity, redundancy in inventory and business continuity planning all come out strongly significant and positive in predicting profitability. This group also has more potential disruptions, but these frequency seems to be identified with better performance, suggesting that firms that operate in these environments become stronger and gain competitive advantage. We intuit that this unexpected result is because the environment is triggering an organizational culture that is ready to face potential disruptions. This finding is consistent with Sheffi (2015) who argues that resilience may result in benefits to a firm. To develop a culture of resilience is beneficial for the firm in everyday business challenges, while insurance only protects the firm from specific pre-considered scenarios.

These results are also consistent with Fiksel (2015) who states that since resilience is a monetary investment, firms have to understand what they need. It would be a waste of money to have unnecessary built-in flexibility for example. Ambulkar et al, (2015) concluded that firms need to learn from disruptions to develop resiliency. Park et al, (2016) addresses the issue from a risk-taking perspective. They find that firms that tend towards higher risk-taking also tend to develop more security measures and safety compliance. Our findings support this result, and we recognize that more research is necessary to better understand the internal dynamics of these relationships.

The results for days of inventory seem to suggest that the first level of resilience is to keep safety stock. There is a tradeoff between resilience and efficiency

documented in the literature. This tradeoff is due to the costs of resilience and the pressure for leaner and more efficient operations (Fiksel, 2015). However, Tang (2006) proposes that the resilient firm should also be efficient. Our findings indicate that it is good for a firm to keep a higher inventory, but we do not think this result is contrary to the lean manufacturing literature. We cannot, based on our findings, argue that limitless inventory would mean higher performance. We can, however argue that there is evidence for resilient measures, specifically inventory and that a deeper study that focuses on inventory strategies is necessary to resolve the conflict in the literature.

Geopolitical risk was not significant in all the models. We think this finding might be partially due to high correlations between geopolitical risk and labor costs. We also think that this particular risk is very difficult to assess, since it is possible for a country to be high risk in political stability but not cause a disruption for years. In this case, firms could benefit from the lower costs that this country offers for a long time before there is a geopolitically-motivated disruption. On the other hand, natural disaster risk provides a more accurate risk to estimate, because the score can be based on statistical data instead of perception.

Based on our results, we reach the following conclusions: 1) In order to operate in a global market, firms that develop a culture of resilience can obtain higher performance. 2) The depth of the resilience necessary to gain competitive advantage depends on the level of risk that the firm faces. 3) Environments that present predictable disruption risks, such as having operations in hurricane zones, can provide

learning experiences and training for other unexpected events. Firms can acquire useful knowledge on how to operate at these sites.

Managers should be aware of these findings when planning how to cope with potential disruptions. It is important for managers to understand the potential disruptions they face and assess the actions necessary to cope with the environment without investing too much money into unnecessary measures, on the contrary, too little money due to lack of awareness on the impact of disruptions.

APPENDIX A: ROBUSTNESS CHECKS

In order to check our results, we ran some alternative models taking into consideration the high correlations between some independent variables and possible endogeneity. Days of inventory and gross margin are endogenous variable. To check our results considering this issue we ran some models lagging the days of inventory variable. We also ran a seemingly unrelated regression (SUR) model following the models for gross margin and days of inventory in Moser et al (2017). The SUR model assumes correlation between the standard errors of the two equations and estimates the coefficients and standard errors according to this assumption.

We also ran models using different variables to control for size. We use Employees and revenue in different models. Model 9 uses a log transformation of Employees to compensate for the distribution of this variable. Since the variable that explains the most a year's gross margin is the gross margin of the previous year, we show some models with a lagged gross margin variable. These models significantly increase the value of R^2 .

There are high correlations between minimum wage and the risks scores and between Countries and events variables. We check for multicollinearity using a VIF test. All values are within the acceptable threshold of 10, but we also ran some models omitting correlated variables. Nine alternative models are shown below. As can be seen, the different models change significance levels for some variables. The results for the risks and the resilience variables do not change signs when they are significant. Finres, events and DOI show stable results. Model 9 with lagged DOI and log transformation of Employees shows consistent results with the models ran on this

paper. The SUR model shows consistent results for natural disasters risk, financial resilience, disruptive events and days of inventory. We also show below VIF results and added variable plots for model 9. The plots show no distinguishable patterns for any of the variables except DOI that has a slight linear tendency towards gross margin.

We tested model 9 to see if it fulfills OLS normality assumption. The graph is shown below and it can be seen in Figure 3 that the distribution of the residuals approximates a normal distribution. We also performed a Jarque-Bera test for normality. The Chi Square value gives 8.546 while the JB value is 0.0139. Since $0.0139 < 8.546$ the null hypothesis of normality cannot be rejected. This test validates the results obtained using an OLS regression.

For long term models we also ran models using variables for 3 and 5 years. The results for these models are also shown below. Results do not change significantly when using different versions of the different years' standard deviation variables.

Variable	1	2	3	4	5	6	7	8	9
Crit Parts								-0.00002 ***	
Geo	-0.0314	-0.0354	-0.0280	-0.0219	-0.0034	-0.0035	-0.0391	-0.0339	-0.0244
Natural	0.0154	0.0251	0.0272 *	0.0310 *	0.0025	0.0027	0.0286 *	0.0156	0.0216 *
finres	0.0176 ***	0.0178 ***	0.0182 ***	0.0186 ***	-0.0006	-0.0006	0.0195 ***	0.0182 ***	0.0206 ***
DOI	0.0015 ***	0.0015 ***	0.0015 ***	0.0014 ***				0.0015 ***	
RecRes	0.0322	0.0290	0.0305 *	0.0289	0.0117 ***	0.0116 ***	0.0397 ***	0.0382 *	0.0376 **
events	0.0038 ***	0.0014	0.0014	0.0013	0.0003	0.0002 ***	0.0016	0.0037 ***	0.0038 ***
mwage	-0.0001	-0.0001	-0.00002	0.00000	0.00001	0.00001	-0.0001	-0.0001	-0.00003
Countries	-0.0102 ***				-0.0003			-0.0082 **	-0.0089
Employees				-0.0005 ***					-0.0118 **
Revenue			-0.000001 ***						
lag GM					0.9640 ***	0.9653 ***			
lag DOI					0.00004	0.00004	0.0015 ***		0.0012 ***
_cons	0.3318	0.2685	0.2179	0.1770	-0.0035	-0.0058	0.2630	0.3418	0.2807
N	217	217	217	217	217	217	217	217	213
R²	0.35	0.32	0.33	0.32	0.98	0.98	0.35	0.37	0.39
industries	28	28	28	28	28	28	28	28	28

Significance levels: *** .01, ** .05, * .1

SUR Model

	DOI	Gross Margin
Geo		-0.0256
Natural		0.0321 ***
RecRes	4.4590	0.0301
events		0.0014 **
finres		0.0189 ***
DOI		0.0017 ***
mwage		-0.000003
Countries	0.0978	
gmargin	34.1871 ***	
Revenue	0.0003	
COGS	-0.0004	
lagDOI	0.7698 ***	
Employees	-0.0170	-0.0004
_cons	3.2507	0.1614
N	213	213
R²	0.84	0.32

Significance levels: *** .01, ** .05, * .1

Variable	VIF	1/VIF
mwage	8.87	0.112735
Geo	6.20	0.161163
Natural	2.68	0.372819
events	2.60	0.385210
Countries	2.46	0.406031
lagDOI	1.29	0.774217
RecRes	1.27	0.786482
logEmployees	1.20	0.836042
finres	1.08	0.928481
Mean VIF	3.07	

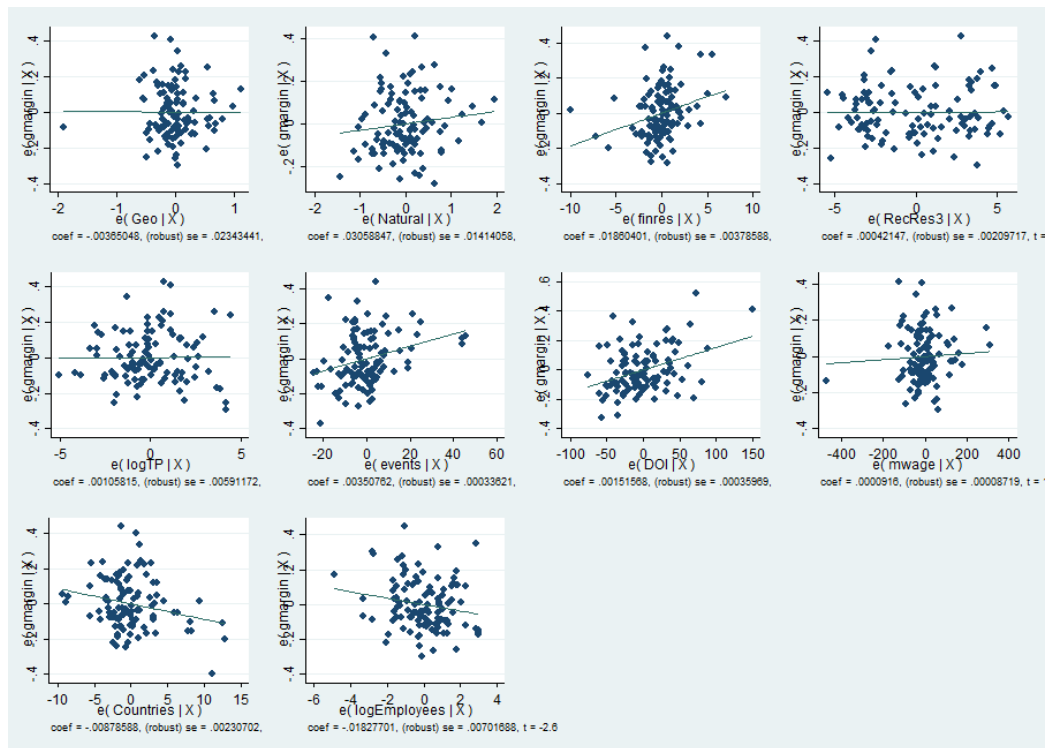


Figure 2: Added Variable Plots

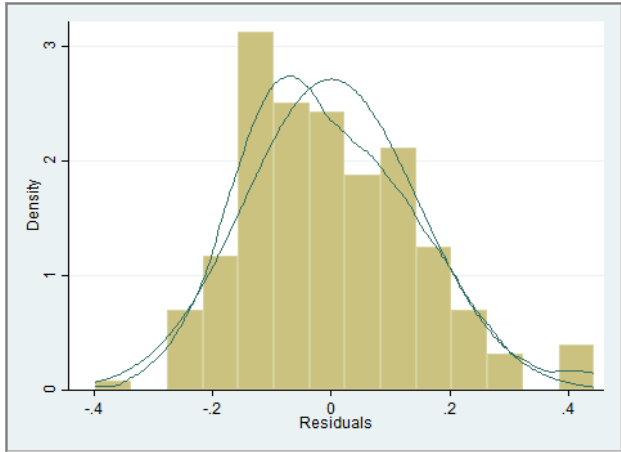


Figure 3: OLS Residuals for Model 9

	DV = Gross Margin (3yrs)			DV = Gross Margin (5yrs)			DV = Gross Margin (10yrs)		
	1 ALL	2 Group 1	3 Group 2	4 ALL	5 Group 1	6 Group 2	7 ALL	8 Group 1	9 Group 2
	RecRes = Yes		RecRes = No	RecRes = Yes		RecRes = No	RecRes = Yes		RecRes = No
CritParts	-0.000146 ***	-0.000148 ***		-0.000133 ***	-0.000141 ***		-0.000140 ***	-0.000136 ***	
Geo	-0.2351	-0.2533	-0.1773	-0.1991	-0.2043	-0.1057	-0.1592	-0.1889	-0.0576
Natural	0.0288	0.1259	-0.0275	0.0448	0.1517 *	-0.0184	0.0822	0.0909	-0.0034
finres	0.1096 ***	0.1034 ***	0.0858 *	0.1121 ***	0.1028 ***	0.0735	0.1210 ***	0.1113 ***	0.0432
DOIsds	0.5572 ***	0.6972 **	0.4501 **	0.4610 ***	0.6859 ***	0.3089 *	0.4829 ***	0.8699 ***	0.3019 **
RecRes	0.1936 ***	0.0179 *		0.1897 ***	0.0210 **		0.0214 **	0.0171 **	
events	0.0150 ***	0.0138 ***	0.0191	0.0158 ***	0.0138 ***	0.0152	0.0140 ***	0.0120 ***	0.0193
mwage	-0.000505	-0.000103	-0.0006	-0.000413	0.000016	-0.0004	-0.000375	-0.000145	-0.000424
Countries	-0.0414 **	-0.0372 ***	-0.0423	-0.0441 **	-0.0360 **	-0.0417	-0.0290	-0.0315 **	-0.0260
_cons	1.1839	0.8795	1.3217	0.8760	0.5067	0.8263	0.7561	0.8534	0.4936
N	203	117	86	203	117	86	203	117	86
R²	0.32	0.41	0.18	0.27	0.39	0.10	0.2362	0.4334	0.058
industries	14	12	13	14	12	13	14	12	13

Chapter 3: The impact of Internal and External Disruptive Events on Supply Chain Resilience Strategies

ABSTRACT

This research study seeks to understand the impact of supply chain disruptive events on a firm's supply chain resilience strategies. We look at two resilience strategies: business continuity planning and recovery time. We use a sample of 159 publicly traded firms and external and internal risks and disruptive events in the year 2014 to test our hypotheses. Our findings indicate that external disruptive events increase the probability of a firm developing a business continuity strategy while internal disruptive events might not. However, once the business continuity strategy has been put in place, internal disruptive events are associated with faster recovery. Our findings also show that firms operating in riskier environments tend to be more likely to have business continuity plans in place. External risks are associated with slower recovery time.

INTRODUCTION

The year 2017 was a very active year for hurricanes. Hurricane Harvey devastated Houston in August 2017, hurricane Irma struck the Caribbean at the beginning of September and hurricane María destroyed Puerto Rico, leaving the entire island without power for weeks, on September 20th. Natural disasters interrupt normality for countries, governments need to assess the situation and ensure the safety of the people to reduce fatalities and to ensure that needed services like health care services are reinitiated as soon as possible after the storm has passed. But not only governments are involved, disasters have a strong impact on business and due to the global economy we live in, a disaster in one country can easily have a global impact.

In the past decade firms have become more aware of supply chain disruptions and supply chain risks. Researchers have looked at the identification and definitions of risks (Ritchie and Marshall, 1993), the impact of supply chain risks on performance (Wagner and Bode, 2008) and possible strategies to mitigate the risks (Christopher and Peck, 2004). Supply chain resilience has been identified as one of the most beneficial mitigation strategies. Sheffi (2005) in his case studies of supply chain disruptions investigation, concludes that a culture of supply chain resilience is more beneficial to the firm than a strategy of solely hedging through insurance for example, because the insurance protects against very specific damages while resilience can improve the processes of the firm and allow the firm to recover from

unexpected disruptions that insurance would not cover because they are unpredictable.

Our study seeks to understand better the relationship between disruptive events and supply chain resilience strategies. It is important to make a distinction between supply disruptions and disruptive events. A disruption is an event that interrupted the normal flow of materials at a firm level and impacted the firm. Hendricks and Singhal (2003) identified disruptions through public announcements of issues with delivery and production. Disruptive events are events that could potentially cause disruptions but that did not necessarily become an issue to the firm. Every year there are hurricanes during the hurricane season, for example, but not all of them become a disruption for firms or an entire industry like hurricane María did in 2017. Hurricane María impacted the pharmaceutical and medical devices industries by paralyzing production in Puerto Rico for weeks.

These disruptive events can be internal or external. Product recalls are events that are not caused by the geographical environment that the firm is operating in, but by the nature of a product and the internal organization dynamics of how the product is designed and managed. Although recalls are a public announcement for the firm according to regulations in the United States, depending on the severity of the reason for the recall they might not necessarily become a firm level disruption.

Our study looks at two types of disruptive events, internal and external to the firm and seeks to understand the impact these events have on the firm's supply chain resilience strategies. We look at two different strategies, the presence of a business

continuity plan and the projected average time it would take a firm to recover from supply chain disruptions.

LITERATURE AND HYPOTHESIS DEVELOPMENT

Supply chain resilience has become an important topic for both researchers and practitioners over the past decade. In their literature review, Kamalahdi and Parast (2016) found academic research activity on supply chain resilience since 2001. Moreover, they note a tremendous surge in resilience research since 2011 following the Japan tsunami of 2009, given the attention to resilience in the news due to the great disruptions the tsunami caused the automotive industry.

One of the contributions of Kamalahdi and Parast was to propose a comprehensive definition of supply chain resilience, which is the definition we use for our study:

“Supply chain resilience is the adaptive capability of a supply chain to reduce the probability of facing sudden disturbances, resist the spread of disturbances by maintaining control over structures and functions, and recover and respond by immediate and effective reactive plans to transcend the disturbance and restore the supply chain to a robust state of operations.”

This definition clearly defines three phases of resilience: anticipation or proactive planning, resistance to the spread of disturbances after the event, and recovery and response. In this study, we use the framework developed by Kamalahdi

and Parast to shape our investigation. Disruptions to the supply chain can be very costly to a firm. In his book, *The Resilient Enterprise*, Yossi Sheffi (2005) explores different kinds of disruptions, from a fire at a particular plant, to natural disasters and terrorist attacks. He sheds light on the vulnerabilities of the supply chain, and the monetary impact they can have towards the performance of the firm. He also shows how different resilience strategies can help control a disruption as it is happening, and can help the firm to recover faster and return to a “business as usual” state. Planning strategies, redundancy in inventory, capacity flexibility, redundancy in suppliers, clear communications, visibility and manufacturing postponement, are some of the strategies that he examines. Sheffi concludes that organizational culture is critical to surviving and managing disruptions; specifically a culture of resilience will put a firm in the best condition to survive a major disruption and even gain competitive advantage after the disruption.

Empirical evidence shows, for example, that operational slack strategies, such as inventory slack and capacity slack, mitigate the impact of supply chain disruptions on a firm (Hendricks et al., 2009). However, in the absence of disruptions, investment in slack resources can represent an additional cost to the firm that can be detrimental to the firm’s performance (Fiksel, 2015). A resilient firm should be able to determine how much slack to build in the various parts of its supply chain processes, given that building resilient strategies represents a real cost to the firm (Sheffi, 2005). It should be recognized that resilience is important to firms because it not only can give them a coping mechanism to deal with unexpected disruptions, as a byproduct it can lead to

better performance due to improved processes, better communication, more visibility and clearer decision-making paths (Sheffi, 2005).

In this study we are interested in studying how the impact of supply chain risks and potential disruptions affects supply chain resilience. Specifically, we test the impact of environmental risks and disruptive events, and internal (organizational) risks, on two resilience strategies: having a culture of risk management and agility. We argue that firms operating in risky environments will be more likely to have embraced supply chain resilience culture and strategies.

Supply Chain Resilience Strategies

Christopher and Peck, (2004) introduced four concepts of supply chain resilience that are known as the “four pillars of resilience”: Supply chain risk management culture, agility, collaboration and re-engineering. Most of the strategies in the supply chain resilience literature are associated with at least one of these concepts.

i. Supply Chain Risk Management Culture: Business Continuity Planning

Supply chain risk management involves establishing ways to identify risks, understanding the probability and the potential impact of supply chain disruptions, and identifying ways to prevent their impact. With proper risk management, a firm can make decisions about the investments necessary to put preventive strategies in place.

The first step in risk management is to understand the uncertainties that the firm is exposed to, in order to map the vulnerabilities of the supply chain. For this

reason, a part of the supply chain risk management literature is dedicated to identifying risks and proposing how to make a risk assessment. Tang (2006) presents a thorough examination of the uncertainties faced in a supply chain, and the possible strategies that may be implemented in case a disruption happens. The risks listed are (internal) operational risks, and the solutions discussed help overcome these disruptions. Manuj and Mentzer (2008) propose a risk management model to assess risks and make decisions about risk management strategies in a global supply chain. In a similar manner, Neiger et al (2009) propose an engineering process to identify risks, considering the complexity of the global supply chain. Sheffi (2005) discusses the importance of proactive planning in his book about resilience in supply chain. Knemeyer et al (2009) identified risk analysis tools from the insurance industry to develop a process to help a firm plan for a catastrophic event. To facilitate proactive planning, studies focus on classifying risks to help match risks to management strategies. For example, Rao and Goldsby (2009) develop a typology of supply chain risks, defining five main risk factors: environmental risk, industry risk, organizational risk, problem-specific risk and decision-maker risk. In this study we refer to this typology to classify supply chain risk exposure. We focus our attention on the framework factors: environmental, industry and organizational risks.

Recent empirical studies on risk assessment focus on understanding the impact of doing business under various circumstances, and how these circumstances may impact different aspects of performance. Wagner and Bode (2008) conduct a survey to see the impact of supply chain risk on supply chain performance. They evaluate several dimensions of risk and find a negative relationship between supply

and demand risk and supply chain performance. These studies help managers and researchers understand why it is important to embed risk assessment tools into the supply chain processes and decision making.

The presence of a risk management culture has been empirically found to be an enabler of resilience (Soni et al, 2014), an antecedent of resilience (Mandal, 2012), and a driver of resilience (Ambulkar et al, 2015). Christopher and Peck (2004) define risk management culture by three main traits. 1) Presence of a supply chain representative in the leadership team, 2) Formal risk assessment processes for decision making, 3) Presence of metrics and routine reviews of risks. Once risks are assessed, strategies can be developed to mitigate exposure to the risks identified.

An overall risk reduction strategy for practitioners is known as business continuity planning (BCP). According to the American Production and Inventory Control Society's (APICS) Dictionary, (2005), business continuity planning refers to a set of "plans to ensure that an organization is capable of continuing to deliver products or services at acceptable predefined levels following a disruptive event". The presence of a business continuity plan implies that threats have been identified and evaluated, and that what is needed to recover in the case of an event has been organized and documented so that it can be put in place when a disruption happens. A BCP is a thorough exercise in risk assessment. The supply chain risk management literature has identified the presence of a risk assessment exercise, such as BCP, as an acceptable indicator of the presence of a risk management culture in multiple survey studies (Juttner and Maklan, 2011; Mandal, 2012; Soni, et al, 2014; Ambulkar et al,

2015). Having a business continuity plan is a good indicator of a risk management and resilience culture.

Our first group of hypotheses will examine the impact of two types of supply chain risks and disruptive events on the probability of a firm having a risk management culture as indicated through the presence of a business continuity plan. A risk management culture is an indicator of a resilience culture (Kalahmadi and Parast, 2016). The presence of a BCP across locations in a firm indicates that the leadership is involved in promoting SCRM culture, it is in itself a formal process and for our study it indicates that firms are being evaluated through it. We feel confident this can be generalized to the current global market environment.

Environmental risks are risks that include political instability, natural disaster threat, macroeconomic risk and policy changes (Rao and Goldsby, 2009). These risks are external to the firm and are a consequence of having manufacturing locations in places threaten by the environment. Firms choose such countries because they typically bring significant cost advantages. Lower cost of labor, lower cost of keeping and handling inventory, lower cost of infrastructure, etc. Holweg et al (2011) showed that firms still use an accounting based process to make decisions about manufacturing locations. These processes emphasize the cost advantages of certain countries. Although they conclude that firms should include the environmental risks in their decision making analysis in order to avoid entering into these environments, we argue that operating in risky environments can trigger a learning process in firms that would result in developing a culture of supply chain resilience. A firm that develops a culture of resilience would be able to take advantage of the cost benefits

that operating in a risky country bring and would also take advantage of the learning experience that operating in a risky environment can bring. For the purpose of this study, we combine political instability, natural disaster risk and macroeconomic risk into one measurement of geographical location risk. We pose that a risky external environment will motivate a firm to develop a resilience culture expressed in the form of having a BCP in place:

H1: *The more a firm has identified exposure to external environmental risks the more likely it will be to have a business continuity plan development process.*

The second type of risk we want to look at is internal risk. Per Rao and Goldsby (2009) these could be organizational or industry risks. Organizational risks are firm-specific risks and industry risks are risks that are posed by the industry such as competitive dynamics, input market and product market. Our study looks at supply chain network complexity as a risk source. Requiring a supply chain network with many nodes (production sites) or many components (product complexity) may be due to a combination of firm-specific factors and industry-factors. Having many components to keep track of makes the supply chain more complex by increasing the number of supplier a firm has, probably increasing the number of tiers for production if the product has a complex design and increasing the number of nodes. Having many components could indicate an internal/organizational cultural trait of how the firm designs its products or an industrial trait of the nature of the product being complex and having many components. It could also be due to product variety, which is also an internal/organizational root cause. Unfortunately our sample does not allow

us to distinguish organizational risks from industry risks that is why we combine them to establish our hypothesis. Following the typology of Rao and Goldsby (2009), we classify supply chain complexity as an industry-organizational risk.

Supply chain complexity is recognized as a type of risk in the risk management literature. Blackhurst, Dunn and Craighead (2011), established that the number of nodes is a proxy of complexity and that complexity can reduce resiliency. Moreover, supply chain complexity has been found to increase supply chain disruptions (Bode and Wagner, 2015). Since it increases the probability of supply chain disruptions, we would expect that firms with high industry – organizational risks will also develop resilience measures expressed in having a BCP. Our general assumption is that firms can learn from both the external environment and the internal environment. A complex product to keep track of can represent an opportunity to develop a supply chain resilience organizational culture. We posit that operating a complex supply chain network will encourage firms to develop a resilience culture, in order to counteract the impact of complexity on supply chain risks:

H2: *The more a firm is exposed to industry and organizational risks the more likely it will be to have a business continuity plan development process.*

In this study we seek to understand the impact of disruptive events on developing a culture of supply chain resilience. It is important to make a distinction between disruptions and disruptive events. A disruption is an event that temporally interrupts the normal flow of goods at one or more stages of the supply chain. Hendricks and Singhal (2003) use actual public announcements of business disruptions in their studies. These were identified by production delays or shipping

delays. Disruptive events are events that a firm faces but that, due to the firm's capability to deal with these events, may not interrupt the normal flow of goods of the supply chain. A resilient firm will successfully use its risk management program to put in place effective strategies to prevent disruptive events from becoming actual disruptions.

A firm that operates in an environment with high propensity for disruptive events will learn how to deal with those events, eventually avoiding actual disruptions. A firm that operates in Puerto Rico, for example, would know that from August through November is hurricane season. The firm should have a BCP in place in case of a hurricane, regardless of how many hurricanes actually occur in a given year. Precisely because the threat is present given the environment in which it operates, the firm cannot avoid the risk. According to the National Hurricane Center, from 1981 to 2012 there were 15 tropical storms, 8 hurricanes and 4 major hurricanes per year in the Atlantic zone. Not all of these become a major disruption like hurricane Maria in September 2017. Every time there is a hurricane alert, there are minor disruptions in order to allow the people in Puerto Rico to prepare for the storm. A minor disruption could be just having to close production for one or two days to ensure the safety of the employees and their families during the storm. A firm that operates in Puerto Rico would foresee a certain amount of these events during the hurricane season and would keep a higher level of inventory to ensure business continuity during those days, for example. A firm that operates in Puerto Rico and does not have a process for hurricane season, increases the risk of supply chain

disruptions because it runs the risk of allowing these minor interruptions to become major disruptions. Therefore we pose that:

H3: *The more environmental disruptive events a firm has to face the more likely it is to have a business continuity plan development process.*

Industry-organizational disruptions can be derived from many sources: machine failures, labor force strikes, liability, credit, and quality changes in input, among others (Rao and Goldsby, 2009). In our study we examine one particular industry-organizational disruptive event, product recalls. Product recalls fall under the liability category, “liability is associated with unanticipated harmful effects due to the production or consumption of a firm’s product” (Rao and Glodsby, 2009). Product recalls have also been included in the supply chain disruptions literature. For example, Hendricks and Singhal (2003) included recalls in the disruption dataset they used in their study.

The Hendricks and Singhal (2003) study focused in the impact of disruptions on firm performance, but did not separately examine the impact of recalls. Wowak and Boone (2015) have an infrastructure category for disruptions, but this category includes various reasons for disruptions, aside from recalls. More recently, Zsidisin et al (2016) conducted a study following the methodology of Hendricks and Singal, (2003). They include a moderating variable in their model describing the reason for the supply chain disruption. They categorize disruptions into four categories: catastrophic, infrastructure, regulatory and supply-side. Recalls are included in their dataset but are not separated as an independent variable. The authors find that each category has a different impact on shareholder wealth.

We single out product recalls as our variable for internal disruptive events because recalls can reflect overall firm quality and may be a key disruptor of supply chain performance. Wowak and Boone (2015) conducted an extensive literature review of the product recalls literature. They pointed out that although recalls may cause a supply chain disruption, they are different from other disruptions, since recalls are internal to the firm and therefore somewhat controllable.

Product recalls have been found to be detrimental to firm performance (Zhao et al, 2013). Recalls may reveal more about a firm than other kinds of disruption because they are related to the product of the firm. Safety issues with the product could be provoked by the culture of the firm, while environmental risks (e.g., hurricanes) cannot. Therefore, researchers have taken an effort to understand the drivers of recalls (Bromiley & Marcus, 1989;Wowak et al., 2015), the recall process (Hora et al., 2011) and how the “gravity” of the recall affects firm performance (Haunschild and Rhee, 2004)

Moreover, the literature notes that a firm may learn from its recall experience. Kalaignanam et al. (2013) found that after a firm experiences a large recall, it tends to realize fewer and less severe recalls in the future. Thirumalai & Sinha (2011) found that in the medical devices industry, future recalls tend to be fewer and less severe after having to recall a medical device. Recalls are also disruptive events that may or may not become major disruptions. The action to be taken from the firm depends on the severity of the fault and so does the magnitude of the disruption. We argue that it is possible for a firm to learn from internal disruptive events like it is possible to learn from external disruptive events. We expect recalls to be triggers of a resilience

culture. Firms that have experienced internal disruptions can learn from that experience and invest in developing a resilient culture. This culture can prevent future incidents and also deal with the incident more efficiently in case it happens again:

H4: *The more internal disruptive events a firm has faced in the past, the more likely it is to have developed a business continuity plan process.*

Re-engineering is one of the four pillars of resilience defined by Christopher and Peck (2004). The supply chain resilience literature has identified re-engineering most often with flexibility and redundancy (Kamalahdi and Parast, 2016). Juttner and Maklan (2011) found that flexibility and redundancy decrease supply chain vulnerability in a disruptive event. Carvalho et al. (2012) conducted a case study and simulation investigation to look at the redesign of the supply chain for resilience. They used two resilience strategies, redundancy in inventory (safety stock) and flexibility in transportation. They find that both strategies are able to reduce the impact of disturbances to the supply chain. Out of the two, our study focuses on redundancy. We will look at redundancy in inventory to determine a firm's capacity to redistribute resources in case of a disruption.

Blackhurst, Dunn and Craighead (2011) studied the impact of different factors on resilience. They find that safety stock is a supply chain resilience enhancer. Mandal (2012) uses a survey method to identify the antecedents of resilience. Under his re-engineering construct, keeping the "optimum" level of inventory is one factor identified. Inventory redundancy strategies can achieve a re-engineering effect by allowing a firm to continue to deliver orders to customers even after a disruptive

event is identified and is being counteracted. Resources can be reassigned internally, as needed, while the service continues.

A safety stock inventory strategy that is well designed will cover all the phases of resilience. The strategy can be formulated in anticipation of a disruption. If a disruptive event happens, having safety stock on hand will allow the company to continue delivering orders, providing the firm with resistance to the disruption, which is the second phase of resilience per Kalahmadi and Parast (2016).

Finally, the buffer inventory will help the firm reduce the longevity of the impact of the disruption on performance, making the recovery phase, the third phase of resilience, shorter in duration. A well-designed inventory strategy, combined with a culture of reacting immediately and resolving the disruption, will allow a firm to prevent small and medium-sized disruptive events from becoming larger business disruptions. For this reason, we will look at inventory levels as a re-engineering strategy for this study.

The supply chain risk management and resilience literature suggests that inventory levels should be kept at some level above the lowest necessary level in order to reduce the potential impact of unforeseen events. Empirical findings show that inventory can effectively mitigate the impact of a disruption on performance. Hendricks et al. (2009) found that inventory slack mitigates the negative effect of a disruption on stock value, using actual disruptions announcements and publicly available data. Schmitt and Singh (2012) found through a simulation study involving a multi-echelon supply chain that inventory placement can have unforeseen benefits in the recovery from a disruption. Liu, et al. (2016) present an analytical model that

allows a firm to stockpile inventory to increase resilience. The model operates at a network level by targeting a virtual transshipment effect that proves to be more cost efficient than simply keeping safety stock at a node level.

Since inventory redundancy impacts all the phases of supply chain resilience, we embedded the hypotheses regarding inventory into the two main resilience strategies we are examining. Moreover, we believe that the inventory strategy is a key component of a business continuity plan. Since inventory is also a resilience strategy we expect that firms that keep higher inventory levels will be more likely to have a BCP because we expect them to have a culture of resilience:

H5: *Firms with higher inventory will more likely have a business continuity plan.*

ii. Agility: Recovery Time

In the supply chain literature, agility has been defined as “the ability of a supply chain to rapidly respond to change by adapting its initial stable configuration” (Wieland and Wallenburg, 2013). It has been identified in the supply chain resilience literature as an antecedent, driver or enhancer of resilience (Christopher and Peck, 2004; Blackhurst et al, 2011; Soni et al, 2014; Kamalahmadi and Parast, 2016). Findings from the literature review by Kamalahmadi and Parast (2016), reveal two components of agility in the context of supply chain resilience: visibility and velocity. In this study we focus on the latter. In a risk context, velocity has been defined as the loss that happens per unit of time (Juttner and Maklan, 2011). The lesser the time of disruption the lower the loss. For the purpose of our study, we operationalize velocity

as projected recovery time. This is the time a location calculates it will take to recover from a worst-case scenario disruption. (The loss attached to this time, the revenue at risk, was not provided in the data sample due to confidentiality client privileges.) We use the time component of velocity as a proxy for velocity. Our study is in line with Brandon-Jones et al. (2014) that operationalizes supply chain resilience as speed in returning to the “normal state” after a disruptive event.

The recovery time that we examine may be a function of proactive planning. It is calculated based on an estimation of a risk assessment analysis, not from the actual recovery time resulting from an actual disruption. Given that recovery time is a component of a BCP, for our study we focus on the subset of firms in our sample that have conducted a BCP. To have a BCP requires firms to have provided a definition of the processes and actions to be put in place in case of a disruption. Therefore, these are not a “random” set of firms, but the firms that have already given some thoughts to how to recover from a potential disaster. The BCP facilitates the decision-making process during the period after the disruption. Given this subset of firms, we examine recovery time to understand which factors make this time longer or shorter.

Firms that operate in an environment prone to disruptions may be better able to cope with disasters, given their prior experience and also the depth of the planning that likely entered into the BCP. These firms have developed a culture of resilience, where practices such as business continuity plan are implemented. We expect that firms that operate under higher environmental risks and have a business continuity plan will be more likely to have developed strategies to cope with their environment

in the most agile way possible. We expect the risky environment to make these firms more agile because of the intangible learning experience that the environment elicits.

H6: *The higher the external environmental risk the better performing the recovery time will be.*

Internal risks may be detrimental to agility. Having more nodes in the supply chain network and more critical parts increases the number of transactions and relationships a firm has to maintain to guard against and recover from a disruption. Complexity increases the number of components, products and locations to be tracked. Moreover, complexity increases the need for communications between supply chain nodes, increases the number of decision making points, and enhances the probability for delays in the delivery of raw materials. Although we stated in H2 that complexity will increase the probability of a firm developing a resilience culture, we posit that complexity will be detrimental to recovery time for those firms that have a BCP. In other words, it would be harder to reduce recovery time for a firm with a big and complex supply chain network.

H7: *The higher the internal risk a firm faces, the worse performing recovery time will be.*

Following the same rationale as H6, we expect disruptive events to increase the agility of the firm. Disruptive events would provide “practice” to a firm and it would have a more precise estimate of how much time it takes to recover from different interruptions and it would be more aware of actions that can be taken to make the recovery as fast as possible. We posit:

H8: *The more environmental disruptive events a firm faces, the better performing its recovery time will be.*

In the case of internal disruptive events, since these are provoked by industry-organizational factors, we expect the experience of these disruptions will cause a desire for change. Since change takes time, we lagged these events and propose that experience from such disruptions in the past will have a positive impact on the recovery time.

H9: *Firms that have previously experienced internal disruptive events will have a better performing recovery time.*

Finally, our last hypothesis regards inventory. Inventory redundancy will help a firm reduce the time of the disruption and may even help prevent the disruptive event from becoming an actual disruption. Since, for this set of hypotheses we are examining firms that already have taken steps towards resilience planning by developing BCPs, we would expect higher levels of inventory to reflect inventory slack strategies. For this reason we expect that more inventory should be associated with faster recovery:

H10: *The higher the inventory, the faster the recovery time will be.*

Table 1 presents a summary of the hypotheses with the operationalized variables and the expected signs.

Table 1: Results Summary

Hypothesis	Independent Variable	Dependent Variable	Expected Sign
H1	LocRisk	BCP	+
H2	Sites	BCP	+
H3	Events & Eventsites	BCP	+
H4	Recalls	BCP	+
H5	DOI	BCP	+
H6	LocRisk	Recovery	-
H7	TotalParts	Recovery	+
H8	Eventsites	Recovery	-
H9	Recalls	Recovery	-
H10	DOI	Recovery	-

METHODOLOGY

Data Sources:

In this study we combine data from 3 data sources.

i. Resilinc Data

Our first data source is from the firm, Resilinc. Resilinc provides supply chain risk management services to its clients. The Resilinc software tool allows firms to track their supply chains, as well as their supplier's supply chains, identify vulnerabilities in the supply chains, design resilient strategies, take mitigating actions to reduce vulnerabilities, and receive notification of disruptions using social networks, among other services. A Resilinc customer can use the software to map its internal supply chain and the supply chain of its suppliers, linking bills of materials to

component suppliers and the manufacturing locations where these components are processed.

Resilinc keeps track of news through social media notification, and provides announcements of potential disruptive events affecting a geographical area. Since the locations of a firm are mapped using the Resilinc software tool, the program forwards notifications with impact estimations to firm executives according to a notification hierarchy that is also part of the tool. A customer is able to identify vulnerabilities across supply chain tiers, and identify if the firm will be impacted by a disruptive event and the potential extent of the impact. The customer can also assess the potential risk of its suppliers, its products or the geographical regions in which it holds operations.

Resilinc provided us the population of disruption alerts that were sent during the year, 2014. These events are categorized into 4 types: 1) hurricanes, 2) fires, 3) earthquakes and 4) other. When a potential disruption is identified, Resilinc sends a notification customized for each firm with relevant details such as, the number of sites impacted and the potential revenue impact. The customer has the advantage of immediate notification, and managers can begin to make plans and decisions providing the firm visibility into the disruption and the opportunity to recover from the disruption.

For the purposes of identification, the Resilinc customers are referred to as the “focal firms”. These are the firms that are making investments in developing resilience for their supply chains. There is no information about the focal firm in our data. For this study, we were provided with data from focal firms’ suppliers for the

year, 2014. Our dataset, therefore, is a cross section for the year, 2014 consisting of data related to the supply chains of Resilinc customers. The database contains information on both tier 1 and tier 2 suppliers to the focal firms, but the list of firms in our data is not linked in any way to the focal firms. There is no information about which focal firms a supplier firm in our data is serving. This makes our sample a random sample of individual firms that may or may not be involved in developing resilience.

The Resilinc service includes identifying “critical” production sites for the focal firms. This criticality is most often given by the fact that in those sites critical activities that affect high revenue products are performed. Therefore, an interruption to these sites could have high revenue impact. For example, these sites are often places where single-source activities are taking place. Since these places are linked to high revenue impacts, the risk assessment exercise includes business continuity plan and recovery time calculations.

The dataset often contains information on multiple manufacturing locations per firm. This information includes: 1) site geographical location (country and coordinates), 2) site risk scores (based on country risk scores provided by the Economist Intelligence Unit), 3) recovery time (self-reported analysis of disaster recovery given in weeks), 4) critical parts that are handled at that location and 5) actual potential disruptive events in the year 2014 that affected the geographical area where the facility is located.

We gathered a sample of firms from the Resilinc database that contains all the publicly traded firms and their manufacturing locations. We then matched these firms

to firms in the Compustat database in order to get financial information on the firms. A total of 313 firms matched with Compustat. These are linked to 3,262 manufacturing locations, 75 countries, and 40 industries following a three-digit NAICS code.

Even though the risk scores for each manufacturing location were provided by Resilinc, it is important to note that the geopolitical risk scores originated at the Economist Intelligence Unit (EUI). The EUI provides many services of risk assessment using scores from 1 (lowest risk) to 10 (highest risk). In our study, we use three of these scores to assess the geographical risk associated with a location: Geopolitical Risk, Natural Disaster Risk and Macroeconomic Risk. These are revised and updated every three to five years by the EUI, depending on the score and the country assessed.

ii. Compustat

There are a number of variables that we drew from the Compustat database in that they were not available internally through Resilinc. Inventory data and performance (profitability) data were not available for the sites or the firms in the Resilinc database. Therefore, we captured these data from Compustat. In addition, we use the Compustate database for cost of goods sold, total revenue, number of employees and research and development investment to calculate control variables. We used the year 2014 to calculate the gross margin, days of inventory and other relevant variables to our study.

In addition, we used data for the past 10 years from the industries involved in our study to calculate industry means and standard deviations for some variables (to

control for industry effects). We calculated 3, 5 and 10-year 3-digit NAICS code Compustat industry aggregated data variables for these purposes.

Since only publicly-traded firms present data on Compustat, we excluded observations where these data were not available. We then matched firms from Resilinc to Compustat. The result of this first match consists of 313 firms.

iii. Recalls Data

We also gathered information on product recalls. For this data we selected only three 3-digit NAICS industries. We chose these three industries because they the industries in our sample with the highest frequencies that were manufacturing industries not service industries. Table 2 shows the industries with a description and frequency. We collected recalls data for each firm in these three industries for the past ten years. The recalls data come from two US government sources (depending on the product) that provide public information on recalls: 1) Consumer Product Safety Commission, 2) Food and Drug Administration. The Consumer Product Safety Commission deals with recalls related to regular consumer products, such as toys, electrical equipment, clothes, home artifacts, computers, etc. The Food and Drug Administration contains recalls related to food, medicines, medical devices and cosmetics. Automotive vehicles related recalls are contained in a separate database, we do not have any such recalls in our dataset. These agencies only contain information about recalls in the US. We recognize that other countries might have different expectations and regulations about products and that recalls might be different. We recognize this can represent a limitation when studying global supply chains. Products are manufactured engaging a global supply chain regardless of

where they are sold, we believe that although it might be limited, using the US product recalls databases provides sufficient information about the firm and the product for the purpose of our study. A product that was recalled in the US was not manufactured exclusively in the US. Adding the recalls data reduced the number of firms to 173 in the data base.

iv. Final Database

We started with over 1,000 firms and 25,000 manufacturing locations provided by Resilinc. 325 of the firms were publicly traded with financial information reported in Compustat. 12 firms were eliminated, 4 were duplicates and 8 were name mismatches that turned out not to be the same firm from Resilinc and Compustat. Choosing only three industries for the recalls data reduced the number of firms to 173. Fourteen observations were deleted due to missing data from Compustat. The 2014 cross-sectional sample contains 159 firm-level observations. These 159 firms are linked to 2,036 manufacturing locations that are present in 75 countries. 1,993 recalls over the course of ten years were reported involving these 159 firms. Table 2 shows the three industries included in our data sample with the number of firms in each industry.

Table 2: Industry Descriptions and Frequency

NAICS	Industry Description	Obs
325	Chemical Manufacturing	41
333	Machinery Manufacturing	22
334	Computer and Electronic Product Manufacturing	96

The data that were originally provided at the manufacturing location level were aggregated to create firm level variables. Geopolitical risk, natural disaster risk, minimum wage and recovery time are aggregated to the firm level by calculating the average among the firm's locations. The number of countries in which these sites are located is used as a count variable at the firm level to illustrate breadth of operations. The amount of critical parts that are managed at a location and the events that impacted each site are also aggregated as a count variable to the firm level. Days of inventory and gross margin are calculated at the firm level using Compustat data. The recalls data are aggregated into several variables with different time frames at the firm level. Long term variables for days of inventory and gross margin are also calculated at the firm level.

The 2014 cross sectional database has 159 firm level observations that include: 1) average geopolitical risk score, 2) average natural disaster risk score, 3) average recovery time, 4) number of countries, 5) number of sites, 6) number of parts, 7) number of potentially disruptive events, 8) days of inventory, 9) number of recalls, and other calculations involving these variables. More details on these variables are provided in the next section.

Variables:

Environmental Risk: Manufacturing Location Risk

Three risk measures were provided for each manufacturing location. The Geopolitical risk score is assigned a value from 1 to 10, depending on the country where the manufacturing site is located; 10 being the highest risk and 1 being the lowest risk. The EIU assigns these values according to a proprietary algorithm that

considers the probability of the country being invaded by another country, having a coup, entering into a war with another country, having a big change in government (example, going from democracy to dictatorship) and other political risks.

The Macroeconomic risk score is also originated at the EIU. This measure considers the probability of a country's economy collapsing, like it happened recently to Venezuela or less recently to Greece. This score also ranges from 1 to 10, from lowest risk to highest risk.

Natural Disaster risk score considers the probability for the country to have a natural disaster. Hurricanes, earth quakes, typhoons, tsunamis, tornadoes, are all considered in this score depending on the geographical region of the country. These scores are reevaluated every 3 to 5 years.

For the purpose of our investigation, we calculate a location risk score (LocRisk) using these 3 scores. The three risk scores are added for each location. To aggregate to the firm level, a weighted average is calculated so that if a firm has multiple locations in the same country, this weight is reflected in the location risk score. The location risk score ranges from 1 to 10, an average score that combines all three types of risk. We chose this measure instead of evaluating each risk independently after speaking with practitioners and the Resilinc research team. They informed us that when performing risk assessments, practitioners combined the three scores because they are interested in knowing the overall risk of the location in order to take resilience strategy decisions. Location risk, therefore, provides an overall risk measure for operations for a firm. We use this variable to operationalize environmental risk, as defined by Rao and Goldsby, (2009).

Internal Risk: Supply Chain Complexity (Critical Parts and Sites)

The second risk measurement we use combines industry risk and organizational risk, according to the definitions of Rao and Goldsby, (2009). For each manufacturing location that has a contingency plan, there is information on how many critical components are processed in that location. These are components of high revenue products, but due to client privileges we do not have bills of materials to link the components to products. More than 90% of these components are single sourced at that given location. We count how many critical components are processed at each single location. Then we aggregate this count through a sum at the firm level. It is possible that this count variable counts a single component more than once, if this part is processed for different manufacturing purposes at more than one facility. However, we believe this count variable is a good proxy for internal complexity. As it provides information about the number of times that components need to be tracked, analyzed, processed, etc. The more critical parts that have to be processed at different locations, the more complex the internal supply chain network is.

The more complex the product, the more parts it will have and the more critical parts it will have. It is impossible for us to separate product complexity, which is highly dependent from the industry from supply chain internal network complexity, which depends on the decisions of the firm. We are using the total critical parts variable to operationalize internal risks. The information was provided at the location level. The variable is aggregated by adding all the critical parts from all locations of the firm. We call this variable (Total Parts). To control for the industry effect, all models that are ran in this study control for industry. This variable is only available

for the firms that performed a business continuity plan, it is not available to test our first set of hypotheses.

When total critical parts is not available, we use the number of manufacturing sites (Sites) as a variable to operationalize internal risk. The number of sites provides information about how big the supply chain network is by approximating the number of nodes it has. Per Blackhurst, Dunn and Craighead, (2011), the number of nodes is a proxy of complexity that has a negative impact in resilience. Like total critical parts, the number of sites can be an industry condition. We control for this effect by controlling for industry in our model.

Environmental Disruptive Events: Events

The Resilinc database includes over 90 disruptive event alerts that Resilinc tracked during the year of 2014. These were provided with the geographical coordinates of an estimated region that they impacted. The geographical coordinates were matched to the coordinates provided for each manufacturing location in order to identify the sites that were impacted by each disruptive event. The number of events that impacted a site were gathered as a count variable. These were added at the firm level in order to obtain an aggregated variable. This variable is not a count of actual disruptions, such as the variable used by Hendricks and Singhal, (2003). Our variable measures how many potential disruptions or disruptive events the firm faced that year due to disruptions at their manufacturing locations.

Kim et al, (2015) established that not all node level disruptions necessarily lead to network-level disruptions. Our (events) variable provides a good opportunity to look at resilience, precisely because these are not all necessarily network disruptions they

can reveal a firm's capacity to endure a disruption and prevent it from becoming a network-level disruption

Another variable is also used in some of the models that was calculated combining the number of sites and the number of events that a firm had in the year 2014. Events per site (Eventsite) was calculated dividing the total number of events for a firm by the number of sites the firm has in the database.

Internal Disruptive Events: Recalls

In our study, we distinguish between environmental disruptive events and internal disruptive events. We operationalize the internal disruptions through product recalls. In the United States, recalls have to be publicly notified through government agencies that keep record of all recalls. We collected the number of recall announcements for each year for each firm in our database. Depending on the product, data were reported to the Consumer Product Safety Commission or the Food and Drug Administration. Public records of both agencies were checked for announcements.

The recalls data goes from 2004 to 2014. Even though our data set for other variables consists of a cross section from 2014, we collected recalls up to 10 years before because we test if the experience of having recalls in the past impacts the resilience strategies of the firm. Since culture takes a long time to change, we collected information for 10 years. The data are collected by year and aggregated into four variables, all of them count variables: Previous Recalls includes the recalls reported for the past ten years, from 2004 to 2013. Five years recalls (5yrRecalls) includes recalls for the past 5 years, from 2009 to 2013. Last year recalls (2013Recalls) includes the recalls only from 2013. Finally, Current Recalls

(CurrentRecalls) includes the recalls from 2014, the same year as the cross-sectional dataset. The models are run using the different recalls variable to see if our results are robust across different definitions of internal risks (recalls).

Supply Chain Resilience Strategies

i. Inventory: Days of Inventory (DOI)

Since our dataset is a cross sectional dataset, we chose days of inventory (DOI) as our inventory measure. There are different ways in the literature to calculate this variable. We followed Chen et al, (2005) that defined DOI as follows:

$$\text{DOI} = (\text{Total Inventory}/\text{Costs of goods sold}) * 365$$

This measurements were calculated using end of year data.

ii. Risk Management Culture: Business Continuity Planning

Christopher and Peck, (2004) define risk management culture by three main traits: 1) Presence of a supply chain representative in the leadership team, 2) Formal risk assessment processes for decision making, 3) Presence of metrics and routine reviews of risks. Often the presence of a risk management culture has been operationalized in survey studies by capturing the presence of a risk assessment process (Juttner and Maklan, 2011; Mandal, 2012; Soni, et al, 2014; Ambulkar et al, 2015). The firms in the Resilinc dataset that have a business continuity plan, have conducted a risk assessment exercise at the site level, identifying the most probable and most dangerous disruptions according to the characteristics of that site. They then

estimate how long it would take to recover activity in that site in case this event occurs.

Having a business continuity plan in our sample constitutes a thorough risk assessment process for decision making. This variable is the dependent variable used to test the first group of hypotheses. The variable is assigned a value of 0 if the site does not have the plan and a value of 1 if the plan exists. 97 of the 159 firms in our sample have business continuity plan, 62 firms do not have it. These 97 firms have 2,698 sites, while the 62 firms that do not have business continuity plan represent 368 sites.

iii. Agility: Recovery Time

As part of the development of a business continuity plan, each site calculates how long it would take to recover activity to the location in case of a disruption. This measure is then used by the focal firm to assess the risk that the supplier poses to the focal firm. Per Christopher and Peck, (2004) this would also contribute to the culture of risk management. The recovery time was provided in weeks at the site-level. It was aggregated to the firm level through calculating an average among all the sites that belong to the firm. This variable is only available for the firms that have a BCP.

Control Variables

Our study is conducted at the firm level. There are many firm characteristics that can influence our dependent variables and need to be controlled in our models. To control for firm profitability, we include gross margin (gmargin) in our models. Gross margin was calculated as follows: $(\text{revenue} - \text{cost of goods sold})/\text{revenue}$. To control

for size of the companies there are various options. We use research and development investment (RD). We use research and development because the supply chain resilience literature links resilience with innovation (Kamalahdi and Parast, 2016). By choosing RD we also control for innovation. We control for industry effects by running our models with robust clusters for industries. Table 3 shows a summary of the variables with the data source and short description.

Table 3: Variables Summary

Variable Name	Source	Description
Location Risk	Resilinc/EIU	Calculated weighted average combining geopolitical, macroeconomic and and natural disaster risks
Sites	Resilinc	Total number of sites linked to a firm
Events	Resilinc	Number of potential disruptions a firm had in 2014
Eventsites	Resilinc	Number of events a firm had per site in 2014. Eventsites= events/Sites
Total Parts	Resilinc	Number of critical parts the firm is monitoring
Previous Recalls	CPSC & FDA	Total number of recalls the firm had from 2004 to 2013
5 years Recalls	CPSC & FDA	Total number of recalls the firm had from 2009 to 2013
Last Year Recalls	CPSC & FDA	Total number of recalls the firm had in 2013
Current Recalls	CPSC & FDA	Total number of recalls the firm had in 2014
DOI	Compustat	Days of Inventory = (total inventory/cost of goods sold) * 365
BCP	Resilinc	Binary variable based on a business continuity planning being existing or not for each site at a firm
Recovery	Resilinc	Average number of weeks a firm estimates it will take to recover from a site disruption.
Gross Margin	Compustat	gmargin = (revenue - cost of goods sold)/revenue
RD	Compustat	research and development investment for a firm in 2014

Models

To test the first group of hypotheses (H1-H5) we used a logistic regression model. Since we are trying to understand if the factors we have proposed will actually influence a firm into developing a risk management culture through the presence or absence of a business continuity plan, we find the logit model to be the most appropriate one.

Models for BPC: Testing for Supply Chain Risk Management Culture Presence

Model 1

Our first model uses the number of manufacturing locations to test for internal risks and the number of events per site to test for environmental disruptive events.

The model is as follows:

$$BCP = \alpha_0 + \alpha_1(LocRisk) + \alpha_2(Sites) + \alpha_3(Eventsites) + \alpha_4(PreviousRecalls) + \alpha_5(DOI) + \alpha_6(gmargin) + \alpha_7(RD) \dots \dots \dots (Equation 1)$$

Model 2

The second model uses the number of environmental disruptive events to test for hypothesis 3 and leaves out the number of manufacturing locations. The number of manufacturing locations is highly correlated to the number of disruptive events. We decided to run two models alternating the use of these variables to understand the effects better. These two first models seek to understand with a certain robustness the effects of internal risks and environment disruptions.

$$BCP = \alpha_0 + \alpha_1(LocRisk) + \alpha_2(events) + \alpha_3(PreviousRecalls) + \alpha_4(DOI) + \alpha_5(gmargin) + \alpha_6(RD) \dots \dots \dots (Equation 2)$$

Models 3 to 5

Models 3 to 5 use different versions of the variable for product recalls. These models differ in the time frame in which the product recalls are being counted. This is done to verify if the time frame that is being considered changes in any way the statistical results. All three models follow the equation below:

$$BCP = \alpha_0 + \alpha_1(LocRisk) + \alpha_2(Sites) + \alpha_3(Eventsites) + \alpha_4(Recalls) + \alpha_5(DOI) + \alpha_6(gmargin) + \alpha_7(RD) \dots \dots \dots (Equation 3)$$

We run these models using Stata standard package using a robust logistic regression model that is clustered by industry. The robust clustered model adjusts the standard errors of the coefficients according the clusters. In this way, we control for industry effects.

Models 6, 7 and 8

The second part of our investigation concerns the agility with which firms consider they can recover from a disruption. The dependent variable for these models is recovery time (Recovery). Since the dependent variable in this case is a continuous variable, we use a regular linear regression model for this part of our investigation. We use the number of critical parts (TotalParts) to test the impact of internal risks in agility. The two models differ in the variable used for product recalls. Model 6 is as follows:

$$Recovery = \alpha_0 + \alpha_1(LocRisk) + \alpha_2(CritParts) + \alpha_3(Eventsites) + \alpha_4(CurrentRecalls) + \alpha_5(DOI) + \alpha_6(gmargin) + \alpha_7(RD) \dots \dots (Equation 4)$$

Following the same structure but changing current recalls for previous recalls, Model 7 is as follows:

$$Recovery = \alpha_0 + \alpha_1(LocRisk) + \alpha_2(Sites) + \alpha_3(Eventsites) + \alpha_4(PreviousRecalls) + \alpha_5(DOI) + \alpha_6(gmargin) + \alpha_7(RD) \dots \dots \dots (Equation 5)$$

Model 8 uses the amount of recalls in the past 5 years:

$$Recovery = \alpha_0 + \alpha_1(LocRisk) + \alpha_2(Sites) + \alpha_3(Eventsites) + \alpha_4(5yrRecalls) + \alpha_5(DOI) + \alpha_6(gmargin) + \alpha_7(RD) \dots \dots \dots (Equation 6)$$

Models 6, 7 and 8 are also ran using the Stata standard package. The robust clustered model for linear regression allows us to control for industry when running the model.

RESULTS

Table 4 shows descriptive statistics and the correlation table for our sample. As can be seen, none of the independent variables has a very high correlation with BCP. Sites and events are highly correlated at 0.85; for this reason we do not run these two variables together. We created a variable that combines them, Eventsites, in order to resolve the high correlation issue. Sites is also highly correlated with Recovery. Models 6 and 7 where Recovery is the dependent variable do not have Sites as an independent variable for this reason. Events is also highly correlated with Recovery. We use Eventsites for all the Recovery models.

Table 4: Descriptive Statistics and Correlation Table

	Mean	STD	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1 LocRisk	3.92	1.01	1.67	6	1														
2 TotalParts	359	1,481	1	14,153	0.219	1													
3 Sites	21	29	1	130	0.296	0.493	1												
4 events	14	21	0	109	0.315	0.248	0.849	1											
5 Eventsites	0.84	0.77	0	4	0.219	-0.119	-0.136	0.092	1										
6 PreviousRecalls	12	57	0	444	-0.054	-0.049	-0.130	-0.113	0.200	1									
7 5yrRecalls	7	32	0	211	-0.107	-0.051	-0.134	-0.117	0.172	0.928	1								
8 2013Recalls	1	5	0	36	-0.134	-0.050	-0.132	-0.121	0.083	0.904	0.949	1							
9 CurrentRecalls	2	12	0	125	-0.123	-0.039	-0.104	-0.092	0.131	0.651	0.754	0.693	1						
10 DOI	99.84	46.89	21.57	264	0.0128	0.0958	-0.0441	0.0041	0.1032	0.2699	0.2407	0.2791	0.2145	1					
11 BCP	0.65	0.48	0	1	0.544	0.180	0.374	0.340	-0.045	-0.194	-0.228	-0.218	-0.155	-0.019	1				
12 Recovery	14.83	25.10	0	122	0.418	0.508	0.842	0.716	-0.108	-0.113	-0.118	-0.114	-0.088	0.044	0.439	1			
13 gmargin	0.44	0.17	0.07	0.82	0.056	-0.151	-0.134	0.014	0.141	0.171	0.148	0.149	0.165	0.439	0.067	0.010	1		
14 RD	680.77	1,681.78	0	11,537	0.033	-0.043	0.024	-0.026	0.001	0.219	0.128	0.154	0.167	0.173	0.041	-0.002	0.267	1	

Table 5 shows descriptive statistics for the two subgroups in our sample. The group that has a business continuity plan and the group that does not. The group with business continuity planning is our sample for the second set of models that is testing agility through recovery time. The total number of observations for this subgroup is 97.

Table 5: Descriptive Statistics for the two subgroups with and without BCP

	Mean		STD		Min		Max	
	BCP = Yes	BCP = No	BCP = Yes	BCP = No	BCP = Yes	BCP = No	BCP = Yes	BCP = No
LocRisk	4.31	3.24	0.81	0.95	2.67	1.67	5.95	6
TotalParts	538	-	1,780	0	0	0	14,153	0
Sites	28	6	32	9	1	1	130	42
events	19	5	23	7	0	0	109	42
Eventsites	0.81	0.88	0.63	0.94	0	0	3	4
PreviousRecalls	4	22	28	79	0	0	276	444
5yrRecalls	1	14	10	47	0	0	97	211
2013Recalls	0	2	2	7	0	0	17	36
CurrentRecalls	1	4	5	17	0	0	46	125
DOI	100	101	52	47	22	15	284	208
BCP	1	0	0	0	1	0	1	0
Recovery	22.37	-	27.76	0.00	1	0	122	0
gmargin	0.44	0.41	0.18	0.17	0.07	0.09	0.82	0.90
RD	732.15	576.10	1,824.74	1,371.20	0	0.072	11,537	9,086

BCP Models Results

Table 6 shows the results for models 1-5. Model 1 shows location risk is statistically significant and with a positive sign as was expected. Significance and sign stay stable throughout all five models. We find strong support for H1. As expected, the higher the environmental risk a firm faces, the more likely it will be to have a risk management culture to deal with that risk. Sites is also strongly significant and positive. Providing support for H2, that internal risks will also make a firm develop risk management culture. Events per site (Eventsites) comes out with a negative sign and not significant. This result is contrary to what was expected. The negative sign remains stable throughout the models and it is not significant in any of them. However the variable (events) that is used in Model 2 is strongly significant with a positive sign as was expected from H3. The number of manufacturing locations (Sites) provides information about the size of the network of a firm. This

gives an idea of internal complexity. On the other hand, the number of disruptive events a firm faces in a year gives information about the environment and how complex it can become to manage the supply chain. Combining the two things and calculating the number of events per site, should provide information about the potential disruptions with respect to the size. However, these events are linked to geographical locations. It can be that a firm protects itself by also having operations in less threatened places. It could be that this variable is picking up a risk leveraging effect and that might be why it is not significant, even though the two variables tested separately are strongly significant. Therefore, we find statistical evidence to support both H2 and H3. It would be necessary to do further research to understand how they interact.

The most interesting result is the result of H4. The recalls variables come out significant but with the opposite sign as expected. Four versions of the variable were tested. Recalls from the previous 10 years, recalls for the previous 5 years, recalls for the year before and current recalls. The only one not significant is current recalls, which is reasonable because we are looking at the impact on something that is strongly cultural. Effects take time. Models 3-5 provide strong evidence that previous recalls do not lead to a resilience planning strategy. The results for disruptions suggest that a firm is motivated to develop resilience strategies when prompted by environmental conditions but not when having faced organizational failures as recalls in the past.

The results for inventory, DOI, were not significant. There is no statistical evidence for H5. It is important to note that even though there is no significance, the sign is consistently negative, that is the opposite of what was expected.

The control variables, gross margin and R&D intensity, are not significant in any of the 5 models, but do have the expected positive sign. Our variables explain from 34 to 40% of the variance in the sample as it is shown by the pseudo R² values.

Table 6: Results for Logit Model (Business Continuity Plan)

	Model 1	Model 2	Model 3	Model 4	Model 5
LocRisk	1.533 **	1.371 ***	1.518 **	1.511 **	1.524 **
Sites	0.053 ***		0.053 ***	0.053 ***	0.054 ***
events		0.060 ***			
Eventsites	-0.514		-0.497	-0.531	-0.600
PreviousRecalls	-0.007 **	-0.009 ***			
5yrRecalls			-0.017 ***		
2013Recalls				-0.115 **	
CurrentRecalls					-0.043
DOI	-0.002	-0.003	-0.002	-0.001	-0.001
gmargin	2.311	1.873	2.340	2.303	2.184
RD	0.0001	0.0002	0.0001	0.0001	0.0001
cons	-6.248 ***	-5.661 ***	-6.200 ***	-6.178 ***	-6.142 ***
Pseudo R²	0.393	0.349	0.397	0.394	0.386
N	146	146	146	146	146

Significance levels: *** .01, ** .05, * .1

Table 7 shows the results for models 6, 7 and 8. As can be seen in Table 7, location risk comes out statistically significant for models 6, 7 and 8 at the 5% level. The sign is opposite from what was hypothesized. The sign is positive, indicating that firms that operate in a higher risk environment have a longer recovery time. H6 is not supported. H7 is strongly supported, TotalParts is significant at the 1% level in all models with a positive sign as expected. We find evidence that internal risk measured

through complexity makes a longer time required to recover from disruptions. H8 is also supported with a negative sign and significance level at the 5% level. H10 for inventory is not supported, DOI is not significant for any of the models.

The results for the internal disruptive events, recalls, is significant for both previous and current recalls with the expected negative sign at a 5% level for previous recalls and 10% level for current recalls. This is an interesting result because in the first models, recalls came out with a negative sign, suggesting that firms with recalls do not invest in developing a culture of resilience. However, in this second group of models the results indicate that firms that face disruptions like recalls are more agile in recovery. We will discuss possible reasons and implications of this in our next section.

Table 7: Results for Agility Models

Recovery	Model 6	Model 7	Model 8
LocRisk	8.279 **	8.249 **	8.228 **
TotalParts	0.007 ***	0.007 ***	0.007 ***
Eventsites	-5.634 **	-5.610 **	-5.608 **
PreviousRecalls		-0.056 **	
5yrRecalls			-0.173 **
CurrentRecalls	-0.286 *		
DOI	-0.001	0.001	0.001
gmargin	10.906	10.831	10.868
RD	-0.0002	-0.0001	-0.0001
cons	-16.492	-16.506	-16.507
R²	0.303	0.304	0.304
N	93	93	93

Significance levels: *** .01, ** .05, * .1

Table 8 provides a summary of the hypotheses and the findings.

Table 8: Results Summary

Hypothesis	Independent Variable	Dependent Variable	Expected Sign	Result
H1	LocRisk	BCP	+	supported
H2	Sites	BCP	+	supported
H3	Events & Eventsites	BCP	+	partially supported
H4	Recalls	BCP	+	significant, opposite sign
H5	DOI	BCP	+	not supported
H6	LocRisk	Recovery	-	significant, opposite sign
H7	TotalParts	Recovery	+	supported
H8	Eventsites	Recovery	-	supported
H9	Recalls	Recovery	-	supported
H10	DOI	Recovery	-	not supported

DISCUSSION

Environmental and Internal Risk Results Discussion

The results for location risk were as expected for the first part involving the presence or absence of a resilience culture through having a business continuity plan, but were the opposite as expected for recovery time. There is clear evidence that a risky environment will increase the probability of taking measures to survive in that environment. The recovery time results need to be analyzed further. The sample for recovery time is a cross sectional sample that is already in a risk management culture (given that all firms had a BCP). Within this set of data, firms that operate in a riskier geographical environment would take longer to recover. This is an interesting and reasonable result, as we are looking at the average of recovery time across the firm.

Therefore the more disruptive events a firm has to take into consideration and plan for, the longer the recovery will likely take.

Another possible reason for this result is that when firms make these plans, they consider worst-case scenarios. Firms that are more used to the risk of the environment will have a better sense of what it will take to go back to normal, making for longer recovery expectations.

Another aspect to consider when looking at these results is that the business continuity plan is done often separately from other contingency plans, such as inventory. In fact, the days of inventory did not have a significant outcome in any of the models, suggesting that inventory levels do not affect the projected time to recovery. Inventory as a supply chain resilience strategy is most likely a separate strategy. Both these strategies would definitely come together when an actual disruption happens and they would both impact the recovery time, but from a planning point of view, decisions and plans about them are done separately.

Recovery time is influenced by other characteristics, such as lead time, the type of disruptions that the firm is considering it might have at each specific location, the understanding of options and time that it would take to understand those options, the nature of the products, and the industry. Unfortunately, we do not have data on these variables. Lead time is highly dependent on the industry and we controlled for industry effects in our models. Our variables explain 30% of the variance for the models of recovery time, providing us with some certainty about the effects of our variables.

The results for internal risks, both for network size and for the number of critical parts proxies, were as expected. Our results link network and product complexity, following the findings of Bode and Wagner, (2015). They found that supply chain complexity increases the frequency of supply chain disruptions. We are finding that complexity also increases the probability of developing a resilient culture and it slows down the capacity to recover from a disruption.

Environmental and Internal Disruptive Events Results Discussion

In our study we separated internal disruptive events from external disruptive events. Following the findings of Zsidisin et al, (2016), we distinguished the type of disruptive event. They found that the reason for the disruption moderates the impact of the disruption on performance. We proposed that the origin of the disruptive event, internal or external will make affect the impact on resilience.

The results for environmental disruptive events are partially supported through the events variable being significant for the business continuity plan in model 2 (although the events per site variable was not found significant). The major results for this type of disruption, caused by external factors to the firm, demonstrate the expected results. They increase the probability to have resilience cultural traits in the firm and they contribute to a faster expected recovery time. This is an interesting finding because it suggests that a risky environment where small and medium disruptive events happen with a certain frequency, a firm could be motivated to develop an organizational culture that is proactive and that can react better to unexpected events, fostering a culture for competitive advantage.

The results for the impact of recalls on the existence of a recovery plan and on recovery time are very interesting. In the first set of models, we get a negative significant sign, indicating that firms that have experienced recalls do not take on resilience practices. This result is opposite to the findings of Thirumalai & Sinha, (2011). They found there could be a learning effect after experiencing a recall. They found that firms that recall a medical device tend to experience fewer recalls. Recalls in our study is an independent variable, while in their study it was the dependent variable. However, a logical expectation from their findings would be that firms that have experienced a recall would build resilience into their supply chain in order to avoid future recalls. Our findings did not follow this logic.

In order to understand our results better, we did a difference of means test between the sample subgroup that does business continuity planning and the subgroup that does not. We tested all four recalls variables to understand if the means were different. The results of this test showed that all four versions of the recalls variable are significantly different for the two groups at a 5% significance level, with the most recent recalls 5yrRecalls and 2013Recalls being significant at 1% significance level. With this additional step, we can say that firms with resilience practices (BCPs) have experience fewer recalls than firms with less resilience practices. It seems that experiencing a recall is not strong enough motivation to develop business continuity plans. Not all is lost. When we look at the results for the recovery time, recalls comes out with a negative sign and is statistically significant suggesting that firms that experience recalls are expecting to recover faster. A reasonable explanation for this would be that the firms that do learn from their recalls

develop ways to recover faster from disruptions and have fewer recalls. This explanation is an interesting finding to investigate in a future study. Our findings seem to suggest that the learning factor that Thirumalai & Sinha, (2011) found in their study is moderated by organizational culture, specifically resilience cultural traits.

LIMITATIONS AND FUTURE RESEARCH

We recognize that there are some limitations to our research. Some of our variables had some limitations that did not impede our investigation but that it would have been more robust to have more detailed information. The Total Parts variable would have been more robust if instead of critical components we would have been able to link the manufacturing sites to finished products. This was not possible due to confidentiality issues. Disruptive events data was only provided for the year 2014, it would have been more accurate if it would have been possible to have data about events over years to match the recalls database. However we were able to set up the variables in a way that the information necessary to conduct our investigation was available for testing the hypotheses.

Our study has focused on the impact of internal and external factors in supply chain resilience strategies. The variable used for recovery time was an estimated variable. Future research could look at how many of the disruptive events actually become a disruption and if the resilience strategies help or not to reduce this

frequency and how long it actually takes to recover once the event becomes a network disruption.

CONCLUSIONS AND MANAGERIAL IMPLICATIONS

Our study contributes to the literature of supply chain resilience. It falls into a group of studies that look at resilience as a dependent variable. Our sample is unique because it contains actual resilience strategies data from a cross sectional sample combined with firm level public data from Compustat. This unique database allows us to study the effect of our independent variables at a firm level. We introduce the impact of geographical location risks using an objective third-party developed score, instead of perceptions from practitioners on the development of supply chain resilience.

We add to the literature a set of variables, actual disruptive events that could impact firms, but that did not necessarily become an actual disruption for the firm. To this time, the disruption variables in the literature were constructed by actual public announcements of disruptions, such as in the studies performed by Hendricks and Singhal (2003), (2005) and (2009), disruptions developed through simulations (Carvalho and Machado, 2007; Carvalho et al, 2012) and case studies and surveys of employees perceptions on disruptions and disruption management (Mandal, 2012; Blackhurst et al, 2011; Brandon-Jones et al, 2014). Our variable adds to the literature by providing empirical information about events that firms have faced before these events become a disruption. We are able to see that these have an impact on

developing supply chain resilience. We also introduce recalls as an independent variable in the supply chain resilience research stream. Recalls have been included in supply chain disruptions studies, such as Hendricks and Singhal, (2003) and the more recent Zsidisin et al, (2016,) but have not been included as separate factor. This is important because our results show that recalls might have a different impact on resilience than other type of events, as was suggested by Wowak and Boone, (2016).

Our first conclusion is that operating in a risky geographical environment is a driver to developing a supply chain resilience culture. Previous literature identifies geographical risk as a negative sometimes hidden effect on performance (Hogwell et al., 2011;Wagner and Bode, 2008), but our findings show that it can be an opportunity for the leadership team to promote and develop an organizational culture of supply chain resilience. A resilience culture is a competitive asset in the current global environment (Sheffi, 2005).

Environmental external disruptive events that do not necessarily become a network disruption can have a positive impact on resilience. Firms that experience more disruptive events tend to be more willing to establish a culture of resilience. This culture could become the factor in the future that helps the firm prevent or survive a big disruption event as suggested by Sheffi (2005) and Sheffi (2015). Factors that trigger resilience are good for the firm.

Firms that have experienced internal disruptive events, such as recalls, tend to not undertake a more resilient culture. However, the firms that are involved in BCP seem to learn to be more agile from having had recalls in the past. This is important

for managers to understand because developing a resilience culture can help them recover from future recalls faster and even avoid having more recalls in the future.

Inventory seems to be an independent resilience strategy that would have to be studied further as the results of inventory from our study do not allow us to make any conclusions about their impact on recovery. This finding may be due to the fact that individual operating characteristics of firms may be greatest determinants of inventory levels. Therefore, there is no systematic relationship between inventory and resiliency.

It is relevant for managers to understand that operating in a risky environment and dealing with the complexity of a global supply chain can be used as an opportunity to develop a more resilient supply chain so that the firm is able to adapt to a volatile environment. Instead of focusing on avoiding supply chain risk, managers can focus on awareness and contingency planning providing the opportunity for firms to enjoy the potential rewards from operating in risky environments and with complex supply chains.

Chapter 4: Future Extensions

This dissertation has highlighted numerous opportunities for future study. There is still a lot to be learned about supply chain resilience strategies that is relevant for supply chain management. The more global operations are the normal way of doing business, the more important this topic becomes.

This study looked at actual disruptive events that firms were exposed to during the year of 2014 and it looked at supply chain resilience mostly on the proactive side of planning. I would like to follow up with a study investigating how many of those disruptive events became actual disruptions for the firms in our sample in 2014. The study would seek to look at an empirical measurement of resilience following Kim et al (2015) definition of resilience as the percentage of node disruptions that did not become network disruptions. Having such a measure would allow us to look at the impact of several firm characteristics on resilience and test empirically if mitigations strategies are effective.

Another interesting question that remains open from our studies is the question regarding inventory. Following the findings of Chen et al. (2005) regarding better performing inventory levels, I would like to make an empirical study identifying lean tendencies and resilience tendencies and comparing the impact on performance of the two strategies.

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