MITIGATING RISK IN PHYSICAL AND NEW PRODUCT SUPPLY CHAINS

By

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ABSTRACT

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Supply chain risk mitigation involves investing in strategic activities that minimize the financial impact of a disruption to the flow of goods through a supply chain or to processes within a firm. Strategic implementation of risk mitigation occurs along the supply chain with a variety of activities such as collaboration, options contracts, and buffer capacity just to name a few. These risk mitigation strategies require significant coordination and investment making it imperative to efficiently allocate resources in order to achieve a positive return on investment. Yet, the effectiveness of many of these strategies is not well known. This dissertation consists of three essays that investigate the effectiveness of risk mitigation strategies, methods for performance evaluation, and contextual factors that influence the interpretation and application of them. Each essay investigates risk mitigation at a different level of strategic decision making, beginning with the highest level, strategic, and proceeding to a more granular level with a focus on tactical and then operational.

The first essay explores how strategic alliances influences new drug development project failures. Developing new products is a complex process that is inherently risky because of the enormous investment needed to develop them and the uncertainty of the product's potential. This risk is most prevalent for pharmaceutical drug development because of the strict requirements set by the Food and Drug Administration and high cost of development. Many organizations are adopting strategies aimed at mitigating this risk, including dispersing cost by alliancing with other organizations. Yet, alliance partners bring additional resources and capabilities to bear on

new product development that may also reduce the likelihood of failure. I show that in early clinical trials, exploratory alliances require alliance partners with diverse new product development expertise to reduce the rate of failures, while in late stages exploitation alliance reduce failure rate if their alliance partners have technological diversity.

Managing supply chain risk requires assessing the exposure a firm faces to various risks and allocating resources to reduce the impact or likelihood of a disruption occurring. Unfortunately, risk is often difficult to accurately quantify, exposing the process to bias by contextual factors. In the second essay, I investigate how these biases may reduce the resilience of supply chains since managing risk requires coordination across business partners. Moreover, this coordination requires consistent terminology of the types of strategies being applied. This study applies the behavior theory of the firm to show that a consistent taxonomy of supply chain risk mitigation strategies can be developed based on their mechanisms of slack. I develop measures of flexibility and redundancy in the context of risk management and address measurement challenges when dealing with psychometric measures related to uncertainty. Using confirmatory factor analysis and generalized structural equation modeling, I show that Japan has a significantly higher level of perceived supply chain risk and significantly lower application of risk mitigation strategies than two western culture countries, the USA and Australia.

The final chapter of the dissertation assesses risk mitigation investments on an efficiency frontier by considering both the cost of the strategies and interdependencies among the different stages of the supply chain, an aspect past work in risk mitigation has ignored. Risk mitigation strategies were measured at the supplier, process, and customer segments of the supply chain and their performance was evaluated simultaneously using a network data envelopment analysis.

This thesis is dedicated to my mother.
Thank you for providing the opportunity and motivation to achieve this goal.

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It is an interesting experience reaching the objective of a goal. Looking back at the time when the goal was set, the end seemed distant and terminal. Yet, achieving a goal is simply another step along our path and ultimately, a short period on the timeline of life. We never fully grasp this until the previously set end point is surpassed. Navigating the journey to a goal requires important guidance since we are unexperienced when we set forth. I am very grateful to all of those whom have helped me reach this major life achievement. The first person I must thank of those individuals is Sriram Narayanan. He was always very encouraging and one I relied on the most to get here. I will be forever grateful for the effort and time he put in helping me become a better researcher in this field. He always encouraged me to work harder and push myself. Sriram led by example and is the hardest working person I know. I always found his philosophy of work ethic interesting because as scholars of operations management, the foundation of our field is to achieve the greatest output with least cost. I suppose you cannot tell your doctoral students to publish as many high quality research papers as possible, but do not work too hard to do so. I laugh and shudder when I think about my first paper I sent him. He encouraged me to write a term paper for his methods seminar on dynamic panel regression models because it aligned with a project we were beginning to work on. I laugh because at the time I did not even what OLS stood for and shudder because of the implications that had on the quality of the paper. Sriram's patience is obviously one of his strongest traits and am thankful above all else, for his patience with me.

Next, I must thank Srinivas Talluri for his role in accepting me into the doctoral program, guidance on my dissertation, and providing a role model for what to become as a professor.

Srinivas's expertise was instrumental in forming my dissertation topic and getting me to the point I needed to graduate. I will never forget his seminar, primarily because he conducted his entire lecture using an overhead projector in a time when they were long since obsolete. Scott Duhadway was my closest friend while working on my Ph.D. and I am thankful that fate had us begin the journey through the program together. There is not another person in this world that has a personality as well aligned with mine to help each other survive the trials and tribulations of getting a Ph.D. in the Supply Chain Management department at Michigan State University. I thank Scott for matching me on enthusiasm and for always challenging me. We always pushed the discussion in our lectures beyond where most Ph.D. students would because we both lacked a filter and refused to accept anything until proven to us. The most memorable experiences I had were with Scott, including transporting our newly bought white board on top of his car with our hands out of the windows while it hailed. It was the largest whiteboard in any office and allowed us to discuss ideas, to keep track of the goals we scored in soccer and the number of advanced words we would sneak into our presentations for Dr. Narasimhan's lecture.

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Chapter 1 – Introduction

"Il n'est pas certain que tout soit incertain."

- Blaise Pascal, Pascal's Pensees

Evolution has ingrained in mankind a risk adverse nature which permeates every dimension of our lives. In fact, risk is so fundamental to human beings that in striving to better understand the risk of death and the afterlife, an entire field of mathematics was born. Statistics has advanced tremendously since its inception and is the one of the most fundamental tools in science. Before statistics was established, mankind already had begun developing complex risk mitigation strategies that resembled modern insurance to distribute risk. The importance of managing risk has only grown with advancements in civilization and statistics. While various types of insurance were adopted before the Common Era, insurance became more sophisticated and widespread practice during the enlightenment with the growth of maritime trade. Today, international trade connects the world and the operations of countless firms, requiring continual improvement in risk mitigation strategies. Developing a better understanding of the effectiveness of these strategies is paramount in advancing supply chain and operations management. This dissertation focuses on this objective by addressing the research question: Why do organizations adopt various risk mitigation strategies and how effective are they in reducing the impact of disruptions to operations?

This dissertation addresses this research question by investigating risk mitigation strategies at different levels of strategic decision making. Supply chain risk is not isolated to any specific strategic level, be it strategic, tactical, or operational. Additionally, strategies implemented at one level, may have consequences at others. Thus, to have a more thorough understanding of risk mitigation strategies, each level must be studied. To achieve this aim, the first essay investigates strategic alliances in the context of new product development to show how alliance may reduce the rate of failure in new product development projects. At the tactical level, the second essay builds constructs of redundancy and flexibility based risk mitigation and shows how they differ across regions. Finally, the last essay develops a performance measurement system for these strategies to improve their application at the operational level.

Managing supply chain risks fall into four stages: identification, assessment, mitigation, and response (Chopra and Sodhi, 2004; Manuj and Mentzer, 2008). Identification is the first step because no action can be taken unless there is a realization that action is necessary. The risks that were identified then must be assessed. Assessment is the stage in which the severity and likelihood of risks that affect the supply chain are established (Zsidisin et al., 2004). Once the potential impact and likelihood of various risks are known, a firm then must decide how to mitigate them. Mitigation is a critical step in the supply chain risk management process because it is the stage that firms execute strategies based on information from the previous two steps. The last stage is response, and occurs after a disruption has happened. All firms must respond to disruptions, but firms that have performed the previous three stages are better equipped to handle disruptions.

I argue that mitigation is the most valuable stage in supply chain risk management and is the focus of this dissertation. While identification and assessment are key components of mitigation, they do nothing to directly reduce the negative impact of disruptions (Kern et al., 2012). Risk mitigation is defined as “Supply risk mitigation comprises the actions used to eliminate, diminish, or counteract supply risks” (Hoffmann et al., 2013). The final step, response, is simply a necessity after a disruptive event occurs. Responding to a supply chain risk will be much easier with effective mitigation tools in place. Response can also be a form of a reactive mitigation strategy (Thun et al., 2011). The effectiveness of the response is directly tied to the mitigation strategies that are in place. Additionally, mitigation strategies cannot be successfully implemented if supply risks have not been identified and assessed. Therefore, risk mitigation implies the inclusion of both identification and assessment.

In line with the organization of this dissertation, I study the effectiveness of risk mitigation strategies to risks that threaten each level of an organization since mitigation strategies must match the risk they are intended to mitigate. For instance, creating product portfolios presents risks at a strategic level, thus mitigation strategies such as engaging in alliance partnerships are the appropriate level of analysis and the topic of my first essay. At the tactical level, having redundant suppliers mitigates risks associated with natural disasters, political instability, quality or capacity issues, and any other problems arising at the supplier's site. However, tactical decisions such these must account for the increase in governance costs and economies of scale that result from investing in these strategies. Operationally, ensuring continuity in production requires reducing the many risk factors stemming from suppliers, quality control, demand distortion, among others. Operational risk mitigation strategies firms can use are multiple supply sources or safety stock. Carrying excess inventory and having multiple supplier poses tradeoffs. For instance, safety stock can buffer disruptions from the supplier, but if the product becomes obsolete, losses from holding too much inventory can quickly erode the value of mitigating supply uncertainty. Thus, an effective performance measurement system is necessary to efficiently allocate resource among the many types of mitigation strategies available and is the focus of the final essay in this dissertation.

The first essay from my dissertation seeks to understand how firms mitigate the risk of new product development (NPD) failure. In general, past research has been focused on strategies to improve new product success, but avoidance of project failure is a fundamentally different perspective that is highly relevant to current practice. An important risk mitigation strategy used in NPD is to engage in strategic alliances in order to share the cost of project failures. However, cost is only one of the variables in determining risk and the effectiveness of alliances at mitigating risk is incomplete without a better understanding of how they influence the likelihood of failure. In my first essay of the dissertation, I assembled a proprietary dataset of almost 9000 unique projects in the pharmaceutical industry to study how alliance partners reduce the likelihood of failures in clinical trials. Using survival analysis, I test the effectiveness of exploration and exploitation partnerships as well as the characteristics of alliance partners at mitigating project failures across the different phases of clinical trials. The results of this study not only inform the pharmaceutical industry about the effectiveness of strategies they employ, but it contributes to the literature on how to minimize the risk of premature project failure.

In the second essay of my dissertation, I explore how culture influences the perception of risk and the ways firms mitigate them. Based on the foundational work of the psychologists Kahneman and Tversky, I expect risk perception to partially be a function of culture. For this study, I apply the organizational theory of slack to differentiate two types of risk mitigation strategies: flexibility and redundancy. I develop scales for redundancy and apply previously develop scales of flexibility in the context of risk management. Further, I examine the differences in scales across cultures by testing the differences between the strategies using a multinational survey with data drawn from Australia, USA and Japan. I address measurement issues by testing whether the scales across the different countries are invariant and then test for these differences by applying a generalized structural equation model.

In the third essay, I extend the previous two by exploring the trade-off between the cost and effectiveness of risk mitigation in supply chains. There is general agreement that applying risk mitigation strategies is good practice, however, the trade-off between the investment in these strategies and how much they reduce the impact of disruptions is unclear. I explore the relative effectiveness of these two strategies in terms of their cost/performance trade-off. In examining this trade-off, I contribute to the literature by first measuring risk mitigation across the different echelons of the supply chain: supplier, operations and customer. Beyond enumerating the trade-offs, mine is the first studies to use a network data envelopment analysis (DEA) methodology in this context to understand the performance of supply chains in a holistic sense with interrelationships among network partners.

Across an organization, many practices are used to mitigate different risks. This dissertation investigates several of them, narrowing the scope of risk management to mitigation practices at different strategic levels. Many scholars focus on a specific domain or strategic level to narrow their research topic. Yet, much can be learned by relating strategies across an organization. My research covers multiple levels of strategic decision making in operations and sourcing management by exploring the effectiveness of mitigation strategies in new product development and supply chain management. Managing uncertainty is one of the principle goals of any firm and has important implications for firm profit and financial sustainability. This dissertation adds to the body of knowledge of risk management by focusing on the strategies firms use to mitigate them, and investigating how, why, and when they are effective at reducing risk.

Chapter 2 - Mitigating New Product Development Risk in the Pharmaceutical Industry

1. Introduction

Pharmaceutical drug sales have reached record levels, but so has the cost of developing them. The estimated cost of developing a single drug today is almost $2.6 billion dollars (DiMasi, 2014). The main contributor to the astronomical price tag of drug development is drug failure. Specifically, failed drugs and invested capital account for more than half of the total cost of bringing a drug to market (DiMasi, 2014). In the clinical trial process, DiMasi (2014) finds that, depending on the molecule, the chances of a drug moving from the initial phase, i.e., phase I, to approval was between 13% to 32%. Failures not only hurt throughput in the drug pipeline of the organizations, but also lock in financial capital putting organization's performance at risk (Schachter and Ramoni, 2007). Thus, it is critical that organizations mitigate the risk of failures in drug development projects. To mitigate these persistent failures, organizations pursue many different strategies to reduce the risk and impact of drug failure, dominant among them is engaging in alliances (Das and Teng, 1998; Rettig, 2000; Khanna, 2012; Gunasekaran et al., 2015).

Alliances in drug development projects serve multiple purposes. First, alliances facilitate sharing of development costs across multiple stakeholders. Not only can partners share the cost of development, they also lower development costs by leveraging their scale and expertise (Rettig, 2000). Second, as organizations look to reduce failures, alliances bring in external competencies to bear on projects. These competencies can be in the form of labor and knowledge (Rettig, 2000). These advantages, in terms of gaining additional resources and engaging external partners, have been shown to improve innovativeness in the new product development environment (Ahuja, 2000; Petersen et al., 2005; Sampson, 2007). The knowledge alliance partners bring into projects, may not only be related to innovation, but also related to mitigating risks. In the context of drug development, against the backdrop of the number of failures that organizations face, alliances might help the organization reduce the cost of development and the risks of project failure.

An integral part of success and failure in drug development projects is the examination of risks that organizations face in this context. In assessing risks, both likelihood and cost of an event are important elements (Haimes, 1998). In this study, I focus on project risk in the context of new drug development projects. While success is an often studied metric in the context of product development relationships (e.g., Rothaermel and Deeds, 2004; Sampson, 2007) failures are equally important in the context of drug development, given the magnitude of failures that organizations face is significant in this domain. Depending on the molecule, failure rates can vary between 68% to 85% (DiMasi et al., 2010). In order to improve this rate either the number of successes needs to be increased or number of failures decreased. Past research on alliances has primarily focused on increasing successes and has shown that they are associated with attributes of the alliance partners in product development projects (e.g., Sampson, 2007), yet their influence on failures is unexamined. Given that the failure rates are significantly higher than the success rates, critical information can be garnered from studying the underlying role alliances play in reducing the risk of failures in the drug development process. Thus, studies exploring the theoretical mechanisms behind understanding failures can contribute to a more holistic understanding of the New Product Development (NPD) process. In this study, I examine this critical aspect by understanding the role of alliances in mitigating project risk in drug development projects.

Focusing on alliances, this study builds on the theoretical framework of exploration-exploitation espoused by March (1991). This framework is appropriate in the context of the pharmaceutical industry because of the progression of the clinical trial process and has been used in previous studies (e.g., Rothaermel and Deeds, 2004). The beginning of the clinical trial process is knowledge intensive where activities involve significant exploration. For instance, steps required at the beginning of the clinical trial process such as population identification, data collection, and study design among others contribute to project specific knowledge. Furthermore, subsequent activities such as the scaling up of trials, selecting site locations and coordinating activities require exploitation of existing knowledge on how trials are conducted. Given that failure rates are systematically different across the different phases of drug development; the role of external knowledge from alliance partners may well differ across the different phases of the development process. Thus, it is important to consider how the impact of external alliances on failures differ systematically by the phase of the trials. In support of this observation, studies, such as Arrowsmith (2011), find that success rates for projects in phase II are the lowest and have fallen from 28% to about 18%. Furthermore, the success rates of trials in phase III is the highest. The differences in success rates across the phases of clinical trials further suggests that the impact of alliances may differ depending on the phase of the drug development process. Accordingly, I examine the impact of alliances across the various phases of clinical trials using the exploration-exploitation framework. Specifically, I define an exploration alliance as an alliance with a partner in early stage environments and exploitation alliance as one with an alliance partner in later stage of the clinical trial environment.

The underlying idea of examining risks within the phases of clinical trials also resonates with the NPD literature. In examining the individual phases of the NPD process, managers make decisions that can minimize risks within individual project phases. Similarly, in order to better understand this phenomenon in the current context, I focus on the phases of the clinical trial process to examine the impact of project based alliances on project failure. This has important implications for managers in crafting strategies that mitigate these risks based on the specific phase of development.

Finally, in mitigating project risks using exploration and exploitation alliances, it is important for firms to be able to appropriately utilize the knowledge and resources of their partners. Partners in complex NPD projects bring in multiple forms of complementary resources that can impact the success or failure of the projects. Past studies in the innovation context have suggested that when partners differ in their knowledge from their focal firm, they are more likely to yield greater levels of innovation (Vasudeva and Anand 2011). Drawing from this stream of research, I focus on understanding how resource diversity that partners bring to bear in drug development projects can impact the risk of failure. This impact may differ depending on the phases of the clinical trial process (early or late) and the nature of alliances (exploration or exploitation). Accordingly, I examine the moderating role of partner diversity on the impact of exploration and exploitation alliances on risks of project failure.

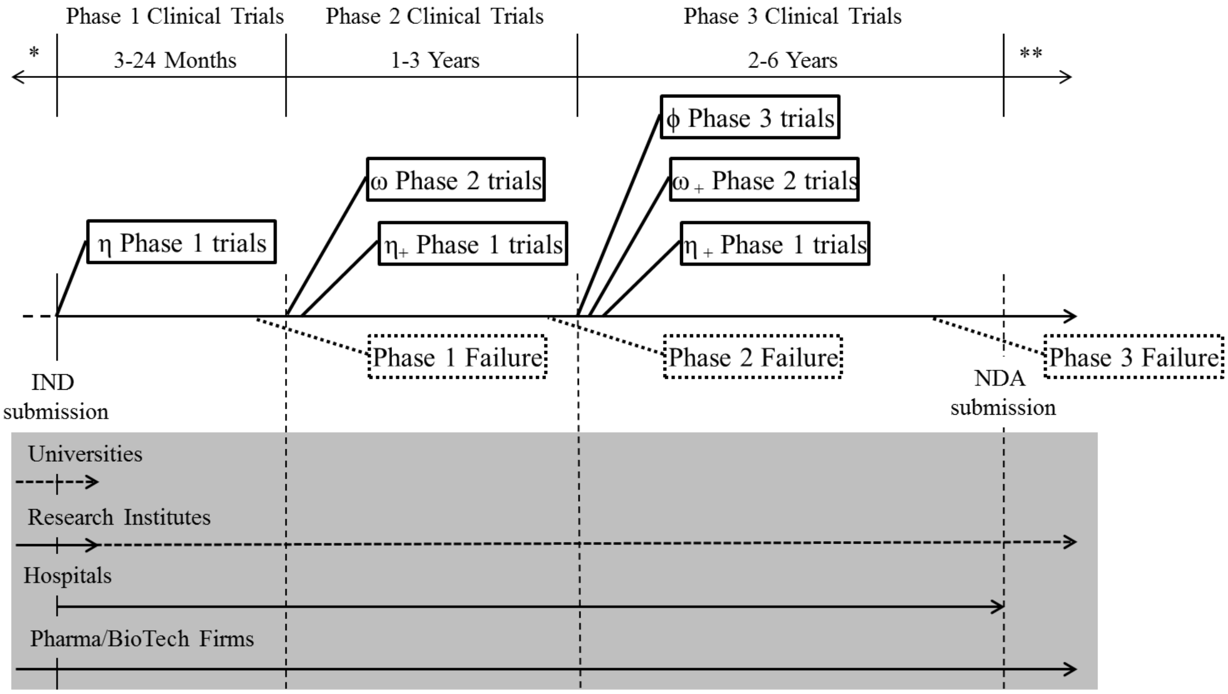
2. Drug Development Process

NPD is a sequence of processes that transforms a market opportunity into a product available for sale (Krishnan and Ulrich, 2001). Developing new drugs, in many ways, is similar to the NPD processes for other classes of products. A key differentiation is that, in the pharmaceutical industry, the process is strictly regulated. Figure 1 shows the process along with the primary organizations involved in the various steps. The process begins in a laboratory, typically with high throughput screening to identify potential drug candidates. Once the molecule has been ‘discovered,’ it is then tested for biological or chemical activity within a specific disease mechanism or pathway. After the molecule shows effectiveness for a specific disease in vitro it is tested in animal models (in vivo). This process can take anywhere between 3.5 years to upwards of 9 years (DiMasi et al., 2014). Once a drug candidate is successfully filtered from the thousands of potential molecules, an Investigational New Drug (IND) application is filed with the Food and Drug Administration (FDA).

Human studies are conducted in association with hospitals and begin with healthy volunteers in phase I clinical trials. Healthy volunteers are chosen because the purpose of the first phase is to determine toxicity in humans. Depending on the drug, phase I trials may last anywhere from a few months to a couple of years and require approximately 20 to 100 subjects. Phase II of clinical trials begins once toxicity is shown to be acceptably low. Phase II trials require a greater number of subjects than phase I and the subject must have the disease. On average, there are between 100 to 300 volunteers recruited for this phase of clinical trials. During this time, the most effective dosage is determined. Once the dosage has been established, the drug advances to the phase III.

Phase III is the largest and most expensive step in the development process; it is also the most critical because it is the final development step before the drug can be approved for marketing. At least two critical trials are conducted, requiring between 300-3,000 patients depending on the condition treated and the drug. At this point, any side effects related to the drug must be discovered along with a continued display of effectiveness in treating the intended disease. If other drugs are currently available to treat the disease, the drug being developed is required to show benefits beyond what is currently available. This phase takes approximately 3 years, but can last twice that long for chronic diseases.

Figure 1. Drug Development Process



Note: Shaded region displays the principal agents in the drug development process and in which stage they are primarily involved in (solid line) and secondarily involved (dashed arrow).
*Preclinical Research takes place before human trails begin indicated by the left facing arrow
**Postmarketing Clinical Trials (Phase IV) may be conducted after approval

The process as described may seem rather simple, but in reality it can deviate substantially because it is merely the minimum requirements set by the FDA. For instance, phase I trials can be designed to give early indications of efficacy rather than just safety. Phase II trials can occasionally be skipped completely or even serve as a final registration trial in special cases. Further complications can arise when the same drug is developed for multiple indications. For each indication, separate phase II and III studies need to be conducted, but the phase 1 trials can be bypassed. In addition, earlier phase trials may be initiated after later phase trials have begun (represented Figure 1 by the + sign after the Greek symbol that represents that phase). For example, a drug may be currently under study in a phase III trial and an organization may initiate a phase I study to investigate the safety of drug-drug interactions for combination therapies or to demonstrate a reduction in the variability of response either between or within patients. These deviations from the standard clinical trial process allow for organizations to have the flexibility necessary to adopt strategies to minimize risks to patients.

The drug development process requires managers to optimize their product development resources in a very complex environment with a high degree of risk that changes as development progresses. In terms of failures, 84% of drug failures are attributable to efficacy and toxicity (Arrowhead and Miller, 2013). The remaining 16% are related to strategic, commercial, and operational structure, such as subject recruitment, infeasible testing procedures, documentation, incidents while testing, portfolio complexity, incorrect market assessment, and lack of experience (Kennedy, 1997; DiMasi, 2001). Theoretically, toxicity and lack of efficacy are factors inherent to the drug being studied, but the design of the study can have implications for discovering these two vital parameters. Medical and laboratory research is notoriously complex and false-negatives or false-positives often occur (Bounansegna et al., 2014). These incorrect assessments of a drug's efficacy and toxicity demonstrate how broadly managerial decisions may impact project failures. This highlights the importance of knowledge and capabilities being applied to reduce the likelihood of project failure in an industry that is one of the most challenging to create new products. Alliances may play a critical role in reducing many of these risks because alliance partners can critically evaluate study design and contribute their expertise to improving clinical trials. Efficient utilization of knowledge resources may reduce the number and rate of failures.

3. Literature Review

3.1 Strategic Alliances in NPD

Strategic alliances are common in pharmaceutical NPD. Firms enter strategic alliances for various reasons, such as differences in resource endowments (Park et al., 2002) or complimentary capabilities (Lorenzoni and Lipparini, 1999). Firms also enter strategic alliances to share the cost of development and reduce their risk exposure. Engaging in alliances reduces the NPD risk by reducing the amount each party invests in development. This allows organizations to invest in products they otherwise would not be able to on their own or to disperse their investment to multiple projects. It also allows access to an expanded network of specialized firms, and their skilled personnel. The benefits of this network has been extensively studied at the firm level from the perspective of positive outcomes, such as innovation (Ahuja, 2000), network strength (Kandemir et al., 2006), and knowledge exchange (Oxley and Sampson, 2004). The gap in alliance literature lies in a lack of research investigating the role alliances play at minimizing the risk of the project under joint development.

The gap may be a result of the assumption that strategies associated with positive outcomes are linearly and inversely proportional to negative outcomes, i.e. a success implies not failing and vice versa. Under closer scrutiny, this assumption may not be valid as strategies directed at achieving positive outcomes may not directly minimize risk. For example, investing heavily in advanced laboratory equipment may facilitate discovery of new drugs and as a result improve the innovativeness of a pharmaceutical organization, but does not necessarily influence the risk of a research project failing. While a project success is the exact opposite of a failure, it is important to understand how investments in strategies aimed at avoiding failure or achieving success may vary together, but are not necessarily required to.

The high cost and likelihood of NPD failure is pressuring organizations to adopt NPD risk mitigation strategies. To reduce risk of failures, organizations may choose partners based on similar risk preferences or risk mitigation capabilities. For instance, Lilly is known for its focus on risk management and went as far as hosting ‘failure parties’ to facilitate learning from failure

(Burton, 2004). Additionally, firms may use partner’s knowhow across the different phases of the clinical trial process to minimize the risk of failure within individual phases of the project. Despite the focus by pharmaceutical organizations on avoiding failures, existing studies in the industry primarily focus on methods to improve the number of successes (e.g., Fang, 2011; Rothaermel and Deeds, 2004; Stuart, 2000). Specifically, research has shown the benefit of strategic alliances, citing linkages to innovativeness (Kotabe and Scott Swan, 1995) and product development (Rothaermel and Deeds, 2004). Thus, shedding light on the relationship between strategic alliance and failure reduction would contribute to a more comprehensive understanding of the NPD process within this industry.

Focusing on the theoretical basis, past studies primarily use the seminal framework of exploration and exploitation introduced by March (1991). From the perspective of the focal firm, exploration and exploitation alliances differ in their learning orientations (Koza and Lewin, 1998). Organizations seek exploration alliances partners in new product development in order to learn new knowledge from their alliance partners (Rothaermel and Deeds, 2004). In pharmaceutical NPD, it could be argued that discovering something new occurs prior to the clinical trial stage. Yet, clinical trials are still fundamentally concerned with discovery, particularly the early stage trials. The important difference is the distinction between discovering a potentially new product and updating a previously discovered product during the development process with new information. Consistent with March (1991), Baum et al. (2000, p.768) define exploration as “learning gained through processes of concerned variation, planned experimentation, and play.” This definition introduces uncertainty in outcomes to exploration. In pre-clinical and clinical trials, this is a key activity. Specifically, early phases (I and II) of the trial process involve significant learning, and possible search of new ideas that are important for the organization to learn about the product, and are characterized by a high degree of uncertainty in outcomes.

March (1991, p.85) defines exploitation as, “refinement and extension of existing competencies, technologies, and paradigms,” which suggests that exploration is relevant for preclinical trials whereas exploitation is critical during clinical trials. In particular, in later stages of clinical trial process, scaling the clinical trial process is a key element to successful execution. The uncertainty in outcomes is significantly reduced at this stage and the value of alliance partners lies in being able to leverage the knowledge gained in earlier phases. In a similar context, Rothaermel and Deeds (2004) find that exploratory alliances are associated with a greater number of products in the pipeline, while exploitation alliances are associated with a greater number of products on the market. Other scholars have also used the exploration and exploitation framework in the context of pharmaceutical NPD process (e.g., Hoang and Rothaermel, 2010; Nielsen and Gudergan, 2012). I also adopt the exploration-exploitation framework to study alliances as a risk mitigation strategy because of the importance these two learning orientations may have for accessing and leveraging knowledge relevant to risk mitigation in different phases of development.

3.1.1 Exploration alliances

Exploratory alliances are primarily intended to facilitate learning from partners (Baum et al., 2000). Learning is necessary for risk mitigation in new product development and testing for several reasons. First, learning improves the assessment of risk with updated information which can improve decision making. In supply chain risk management literature, learning orientation has been shown to indirectly improve risk mitigation in supply chains (Braunscheidel and Suresh, 2009). In order for risk mitigation to be effective, risks must be accurately identified

(Kern et al., 2012). Alliance Partners (APs) improve access to diverse knowledge and information resources (Ahuja, 2000), which may improve the methods of product development and help solve problems with novel solutions. For example, false-positive outcomes are a common source of failure in clinical trials and may be avoided through better study design and identification of issues (Buonansegna et al., 2014). Exploratory alliances may result in improved study design through access to superior information and resultant utilization of information.

As development continues through clinical trials, the impact of exploration alliances will likely vary. In phases I and II of clinical trials, uncertainty about the outcome of the product is at the highest level of all of the phases. Several key activities constitute this uncertainty. These include assessment of drug safety and tolerability, response to dosages, its pharmacokinetic profile, gaining of knowledge related to the mechanism of action and building an understanding of side effects of the product (Buonansegna et al., 2014). A deep understanding of the product is necessary in order for an organization to reduce their chances of failure in these early stages. Exploration alliances are founded on the desire to create knowledge through learning, and that knowledge will be specific to the development project. As development progresses to phase III, the product approaches commercialization and existing knowledge may be better exploited since lower uncertainty will permit greater generalizability of that existing knowledge toward problem solving. In contrast to earlier stages, exploration activity may be less valuable in later stages, since a majority of uncertainty is resolved within the drug development projects. As March (1991) notes, organizations need to balance exploration and exploitation within their development efforts. Such a balance is necessitated as management needs to balance both resources and attention. As an activity, exploration is extremely suited to early stages of development projects where uncertainty level is the highest. In contrast to early stages, firms that pursue exploration alliances in later stages may increase chances of failure. Specifically, exploration alliances in later stages are likely incompatible with the product development process since they may be pursued at the expense of other strategies (exploitation). Furthermore, in later stages, exploration likely takes resources away from focusing on planning for commercialization of the products. Thus, I posit a reduction in risk for early phase of clinical trials, but an increase in risk of failure in later stages of the development process:

HYPOTHESIS 1a: *Exploration alliances reduce the probability of product failure in Phases I & II of clinical trials.*

HYPOTHESIS 1b: *Exploration alliances increase the probability of product failure in Phase III of clinical trials.*

3.1.2 Exploitation alliances

Just as was the case with exploration, exploitation has a variety of definitions, but they differ to a greater extent than those for exploration (Gupta et al., 2006). Despite the differences, the concept of existing knowledge is generally shared within most of the definitions. Benner and Tushman (2002) define exploitation technology as, “involve improvement in existing components.” According to Vermeulen and Barkema (2001), exploitation is defined as “ongoing use of a firm’s knowledge base.” These definitions were chosen because they exemplify the similarity in conceptualization and represent two alternative perspectives on organizational learning. Both specify the trait of the exploited resource as existing, but the first definition retains the same learning element as exploration while the later simply specifies use. How then do exploitation alliances influence NPD risk?

Past research has traditionally associated the type of alliance with the function it serves (Lavie and Rosenkopf, 2006). For example, exploitation alliances have been shown to be more influential on product success at later stages of the NPD process (Rothaermel and Deeds, 2004). When applied for risk mitigation, that functional distinction and associated temporal precedent appears less defined. Whereas exploration alliances reduce risk through learning, exploitation alliances rely on utilizing existing knowledge. Exploitation alliances allow for information to be combined and scrutinized by multiple stakeholders in order to create NPD processes with the least risk. Exploitation alliances may be sought to assist in the successful production, sale, and distribution of that product. While these capabilities are targeted toward the late stages of product development, the formation of and, knowledge leveraged from exploitation alliances may be implemented at any stage of the development process because it already exists. Specifically, steps detailed in one of the stage of the development process to mitigate the product development risks may also find value in mitigating risks in other stages. When forming an alliance, organization thoroughly analyze the feasibility of the project and may contribute input beyond their role that may enhance the risk profile of the project. In environments that require speed in discovery of knowledge, such as pharmaceutical drug development, exploitation of knowledge is essential for survival (Miller et al., 2006). Therefore, adopting exploitation alliance can likely benefit from existing knowledge at any stage in development.

HYPOTHESIS 2a: *Exploitation alliances reduce the probability of product failure in Phases I & II of clinical trials.*

HYPOTHESIS 2b: *Exploitation alliances reduce the probability of product failure in Phase III of clinical trials.*

3.2 Alliance Partner Characteristics

In order to derive the maximum intended benefits from alliances, the specific traits of each alliance partner in relation to one's own are of critical importance. The term diversity is often used in the literature when studying the impact of alliance partner characteristics and diversity in resources, knowledge, and capabilities has been shown to improve alliance innovation performance (Dell'Era and Verganti, 2010; Faems et al., 2005; Phelps, 2010; Srivastava and Gnyawali, 2011). Despite key differences in the timing and objectives of exploration and exploitation alliances, there has not been a thorough investigation to when and which type of diversity is important for each of them. For example, Lane and Lubatkin (1998) note that it is easier for partners to find and exchange knowledge when they have similarity of knowledge profiles. Such similarities can help partners to better exchange knowledge and ideas in each phase of the project resulting in their ability to control the risk outcomes from the project. In contrast, dissimilarities in knowledge profiles can allow for greater learning abilities by pooling resources of the diverse partner base. These pooled knowledge resources can result in greater likelihood of problem identification, and consequent risk mitigation efforts by implementing novel solutions. Postrel (2002), for example, notes that the overall payoff from external knowledge depends on the relative learning costs and the marginal pay-off that organizations expect to gain. Diversity of knowledge between focal firms and alliance partners is a critical component of how organizations can expect to leverage external knowledge. I propose that diversity in partner knowledge characteristics is likely to have an impact on how organization is able to leverage exploration and exploitation alliances to reduce product risk.

3.2.1 Exploration Alliance Diversity

Exploration alliances as previously defined are sought with the purpose of generating new knowledge through learning. As such, the diversity in alliance partners should reflect traits that are specific to the goal. For exploration alliances, knowledge is created through the co-development process. Therefore, diverse NPD experiences of partners are likely an important indicator of knowledge that can be used to explore new knowledge domains. For example, Wu et al. (2015) found that differences in technological profiles of partners, is necessary to improve the design and development of new products. This reflects the primary objective of exploration alliances, generating new knowledge in the form of intellectual property. Past research has examined the differences in partner patent profiles on innovation performance (Vasudeva and Anand, 2011). It is likely that these differences in partner knowledge profiles reduce risks in projects as the differing knowledge bases among the alliance partners allow them to combine their knowledge to search for new ways to minimize failures in projects. Vasudeva and Anand (2011) propose that diversity consists of latitudinal and longitudinal components, referring to diverse and distant partner knowledge, respectfully. I adopt this logic and capture AP's diversity with two measures: NPD complementarity (latitudinal) and partner innovativeness (longitudinal).

I propose that when alliance partner innovativeness is high, it is likely that exploration alliances will be more effective in reducing project risks. While past research has not directly proposed a relationship between partner innovativeness and NPD risk reduction, many of the arguments proposed can be extended to the domain of risk. For instance, Baum et al. (2000) showed that innovativeness of alliance partners improves the success of biotech startups. The authors suggested that alliance partners "…provide efficient access to diverse information and capabilities…[and] provide more opportunity for learning…" (Baum et al., 2000, p. 268). Innovative organizations have experience managing NPD risk, and partnering with them may improve the collection and analysis of information necessary to minimize NPD risk. Specifically, exploratory alliances are characterized by joint learning, discovery and co-development efforts. In pursuing exploratory activities, greater diversity of knowledge in partners is likely to help the firm discover novel information that can be utilized to reduce unseen risks that organizations may face through the process. This can be attributed to greater degree of pooled domain knowledge between the alliance partners. This pooled knowledge can facilitate better identification of risks in the development process. In addition, it is likely that superior identification of risks accompanies search and implementation of superior solutions to mitigate the risks as well. I quantify knowledge diversity with a citation weighted patent diversity measure and refer to it as Partner Innovativeness (*P-Inn.*). Thus, I hypothesize:

HYPOTHESIS 3a: *Partner Innovativeness (P-Inn.) negatively moderates the relationship between exploration alliances and product failure such that when alliance partners have high P-Inn., exploration alliances have a lower probability of product failure than at low P-Inn.*

Beyond partner innovativeness, I expect that the relative experience partners have in developing products in individual phases will also influence risk. Diversity of knowledge domains reflects differences in fundamental understanding across the knowledge domains of activities and processes. Katila and Ahuja (2002) reflect this in their study examining innovation performance after acquisitions. The authors argued that innovation performance of an organization is contingent on the knowledge characteristics between the acquiring and acquired firm. Likewise, differences in process knowledge is likely to promote greater awareness of risk mitigation strategies, more so given the criticality of processes in complex NPD projects. This is likely true in processes such as clinical trials. Consider Dilts et al. (2010) who did an in-depth analysis of phase III cancer trials. These trials involve an in-depth understanding of the process of conducting the trial. Specifically, the process itself had several hundred steps requiring several transactions that span regulatory authorities, patients, and other partners. Similarly, Adams and Branter (2006) note that process related uncertainties in the clinical trial process are a key contributor to the development cost of drugs. Several critical functions span this process including protocol development, feasibility assessment, study contract processes for each stage among others require deep execution knowledge (see Dilts et al., 2013 for an overview of the steps).

When partners possess diverse process knowledge the combination of knowledge related to NPD can reduce the risk of failure as they can better recognize the process risks that may underpin the different phases. Organizations that have most of their products in early stages of development will have a substantial amount of knowledge relating to early development projects. The same argument can be made for organizations with the majority of their products in market. Difference is experience with NPD process between organizations represents complementarity of experience between the partners. For exploration alliances in which firms seek to discover something new, I expect NPD complementarity to improve the knowledge generation required to uncover and avoid NPD risks. Specifically, the diversity of collective process experience among partners is more likely to help in resolving uncertainty involved in exploratory activities. This can facilitate resolution of process related problems more quickly and efficaciously. Accordingly, I hypothesize:

HYPOTHESIS 3b: *NPD complementarity negatively moderates the relationship between exploration alliances and product failure such that when alliance partners have high NPD complementarity, exploration alliances have a lower probability of product failure than at low NPD complementarity.*

3.2.2 Exploitation Alliance Diversity

Exploitation alliances are driven by the opportunity to leverage alliance partner strengths in order to improve the marketing of a product. Therefore, exploitation alliance will likely be influenced by organizational level variables that represent existing knowledge domains that may be exploited. Such variables that have been argued to moderate how alliances impact NPD performance outcomes are power dependence (Álvarez Gil and González de la Fe, 1999) and firm size difference (Kalaignanam et al., 2007). To capture the two components of diversity for exploitation alliances, I utilize partner size (longitudinal) and technological diversity (latitudinal). Large pharmaceutical organizations have extensive experience with downstream development activities (Rothaermel and Hess, 2010). They possess substantial capabilities to exploit opportunities and leverage their experience for the production and distribution process (Pisano, 1996). Accordingly, it is likely that large organizations are better able to improvise downstream activities in the value chain and make adjustments to reduce project risks. Therefore, size would influence the degree that exploitation alliances reduce project risk. Therefore, I hypothesize:

HYPOTHESIS 4a: *Size negatively moderates the relationship between exploitation alliances and product failure such that when alliance partners are large, exploitation alliances have a lower probability of product failure than when alliance partners are small*.

From an organizational perspective, NPD knowledge domains can be observed based on the lines of business they operate in. Organizations operating in a particular business segment are more likely to possess significant knowledge of that industry. Haeussler et al. (2012) argue that internal technological capabilities impact the upstream and downstream horizontal alliances. Exploitation alliances in particular help the organization identify downstream risks and examine countermeasures for the identified risks to reduce failures in the trial process. Further, as argued before, it is likely that greater diversity of knowledge helps identify risks and consequent countermeasures. As organizations broaden the scope of their knowledge, they are more likely to find unseen risks. In order for knowledge assets to be leveraged however, they cannot be completely redundant (Sampson, 2007). Thus, when alliances have greater degree of technological diversity, exploitation alliances are more likely to help in identifying risks early since the greater diversity of knowledge domains embedded within the alliance facilitates superior identification of risks. In line with this argument, Koza and Lewin (1998), demonstrate that exploitation alliances are effective when competencies across organizations complement each other (Koza and Lewin, 1998). Thus, I hypothesize the following:

HYPOTHESIS 4b: *Technological diversity positively moderates the relationship between exploitation alliances and product failure such that when alliance partners have high Technological diversity, exploitation alliances have a lower probability of product failure than at low Technological diversity.*

4. Research Design

I utilized a mixed method approach, combining qualitative interviews with secondary data to use for statistical analysis. I chose the pharmaceutical industry from 1992-2015 as the setting because of the highly regulated NPD process and the risk involved in developing new drugs. The legal requirements of pharmaceutical drug development provide control for the statistical analysis since I am trying to uncover how alliances influence project failure at various stages in development. Managers involved in various aspects of pharmaceutical NPD were recruited for involvement in the study. Interviews were conducted over the phone and lasted between 30 minutes to an hour. The interviews were semi-structured and were used exclusively to ensure validity of the quantitative study. The participants were asked how they view NPD risk mitigation, how frequently they used alliances as mitigation strategies and how the characteristics of their alliance partners influenced project outcomes. Each interview was followed-up after the quantitative analysis was initiated to ensure that the analysis captured risk mitigation without omission of important items.

In order to test the hypotheses, both project level and firm level data was obtained from Medtrack and the US patent office (USPTO). Medtrack is a database that compiles information on pharmaceutical drug development progress, as well as patent, financial, or other related data. Both public and private firms are covered by the database through compiling information from public announcements and other proprietary sources. As a result, over 130,000 products and 30,000 companies are listed in the database. I restrict the sample to products that are currently in development or have failed in phases I-III of clinical trials. Limiting the sample to the three phases of clinical trials minimized sample selection bias since all drugs must submit a New Drug Application (NDA) with the FDA before commencing clinical trials. The final sample included in empirical analyses consists of 8,740 projects in 10 different therapeutic areas over the three phases of clinical development. Therapeutic areas with less than 1% of the total sample were dropped from the analysis. The quality of the final data was checked against previously reported values of the key constructs, alliances and failures. Approximately 70% of the drugs in the sample were self-originated (those being actively developed by the organization who discovered the drug), matching the reported percentage of alliances in a study by DiMasi et al. (2010).

4.1. Measures

4.1.1. Product Failure

I examine the relative effectiveness of various risk mitigation strategies in the three phases of clinical trials. In order to test the hypotheses, I utilize survival analysis since the time it takes a project to fail is the dependent variable. Time to failure is quantified as the total time in days from the beginning of a specific phase of clinical trials and the date it is discontinued. Given the complexities of clinical trials, I use the earliest date of the first trial in each phase as the initial time. The time of failure is the date that the product has been discontinued, suspended, or withdrawn. Medtrack also classifies products as “no active development” if there has not been any reported development of a drug after two years in order to capture unannounced discontinuations. These instances are given a time to failure as two years from the last report, plus the time from that report to initiation.

4.1.2. Risk Mitigation

I explore alliances as risk mitigation strategies in NPD. Following past studies that investigated the relationship between alliances and innovation, I adopt March’s (1991) organizational learning classification to differentiate exploratory and exploitation alliances. Each project in the database contains the names of each company involved in development along with their role. Following Rothaermel and Deeds (2004), a binary variable was created for projects that involved companies involved in co-development as an exploratory alliance. A binary variable was created to represent exploitation alliances for projects that involved companies in sales, marketing, or production.

4.1.3. Alliance Diversity

The effectiveness of risk mitigation through collaboration likely depends on the characteristics of both the focal firm and those of the alliance partner. In order to capture this, I quantify the relative differences in technological diversity, size, innovativeness, and NPD complementarity.

Technological diversity: Technological diversity (*Tech. Div.*) is defined as the number of subfields the APs operate in and is quantified as a count variable (Rothaermel and Deeds, 2004; Shan et al., 1994). The number of technological subfields that are shared by the focal firm and those of their alliance partners are subtracted from this measure so that a large overlap of subfields is not misrepresented as high Tech. Div. For example, if an organization operates in three subfields: Generics, Pharmaceuticals, Stem Cell Therapy and its AP operates in Biotechnology, Generics, Pharmaceuticals, Tech. Div. would equal 1 since the AP operates in 3 subfields, but two of them are shared.

Partner Size: Partner Size (*P-Size*) is recorded for each AP as the total number of products in their pipeline. Partner size is quantified as the average of size for all APs.

NPD complementarity: The measure of NPD complementarity (*NPD Comp.*) captures the average degree alliance partners specialized in different phases of NPD than the focal firm. It is quantified as a percentage difference of products in four stages of development: pre-clinical research, clinical trials, marketed, and discontinued.

$$\frac{1}{j}\sum_{i=1}^{j}\sum_{i=1}^{n}\left|\frac{x_n}{X}-\frac{x_{jn}}{X_j}\right|$$

where x_n is the number of products in development stage n and X is the total number of unique products for the focal organization. Subscript j represents the alliance partners. Absolute values of the differences were summed because the direction of difference is not theoretically relevant and also to ensure that positive and negative differences would not cancel each other out. To illustrate, consider a sponsor company that has 2 APs (P1 and P2) and 10 drugs in development. The sponsor has 1 drug in pre-clinical research, 5 in clinical trials, 2 marketed, and 2 discontinued. P1 has 5 drugs, all in pre-clinical research. P2 has no drug in pre-clinical research, 23 in clinical trials, 12 marketed, and 10 discontinued for a total of 45 drugs in various stages of development. The knowledge that the sponsor can leverage from its two APs depends on their expertise in drug development which is different than its own. The measure is calculated as the average percentage difference between the stages of development. P1 focuses on pre-clinical research, therefore its technological diversity would be: $\left|\frac{1}{10}-\frac{5}{5}\right|+\frac{9}{10}$. P2 is more focused on clinical trials with several products in the market and discontinued: $\frac{1}{10} + \left|\frac{5}{10} - \frac{23}{45}\right| + \left|\frac{2}{10} - \frac{12}{45}\right| + \left|\frac{2}{10} - \frac{10}{45}\right|$. The average of these two values is the final measure of NPD complementarity.

Partner Innovativeness: Partner Innovativeness (*AP Innovativeness*) is captured for each organization as a five year citation weighted measure from the date of project initiation (see below for additional details). An average of this measure is taken for all of the alliance partners involved in co-development.

4.1.4. Controls

I include several controls that have been shown to influence pharmaceutical drug failures.

Size**:** Since the sample consists of both public and private firms, common size measures such as employees or assets were not available for each observation. Therefore, I use the number of products a firm has in development and in the market as the measure of firm size since it is also an asset that varies with the size of the organization. Using a subsample of public firms from the dataset, I verified this assertion by calculating the correlation between the measure of size and the number of employees ($r_{Size \cdot Employees} = 0.835$, *p*<.001, n=7242).

Indications**:** Many drugs are developed for more than one disease. Clinical trial data from one project may be used to minimize uncertainty of other projects. Past research has shown that the more indications a drug is developed to treat reduces the risk of product failure (DiMasi and Faden, 2011). This measure is quantified as a count variable, calculated as the sum of all drugs being developed or have completed development by the sponsor organization that has the same active compound as the drug under analysis.

Number of Companies involved: Since the alliance variables are binary, I also account for the number of firms involved in the process from the beginning of development. I do so because as the number of companies involved in development increases, the potential access to knowledge and resources widens while the difficulty in project coordination may also increase. This variable (*Co*.) is quantified as a count variable to account for these potential effects on failure rate.

***Licensing*:** Beyond alliances, purchasing of intellectual property can also be accomplished via in-licensing. To account for the difference between self-originated compounds and the products being developed jointly, I control for licensing contracts by including a binary indicator equal to 1 if the compound was in-licensed and 0 otherwise.

***Innovativeness*:** More innovative organizations may fail at NPD less because they are simply better at NPD than other organizations. I adopt the measure of innovativeness used by Dutta and Weiss (1997), which is an industry adjusted five-year trailing citation weighted measure. For every project, patent citations were summed five years prior to the first date of project initiation and divided by the average five year patent citation count for that organization's industry based on MedTrack's classification of industry. The USPTO database was used to develop this measure to limit differences in patent systems (Nagaoka et al., 2010) and because the majority the companies in the sample are located in the United States.

Table 1. Data Summary

Variable	Description	N	Median	Mean	σ	Min	Max
Development time	Time in days from the beginning of clinical trial to discontinuation of product development						
Phase 1		1139	851	1053.82	678.85	21	4749
Phase 2		2873	1095	1270.67	791.96	10	5536
Phase 3		557	1227	1417.68	961.08	11	5791
	Time in days from the beginning of clinical trial to censored date						
Phase 1		1135	619	906.33	816.69	3	5148
Phase 2		2071	814	1091.27	953.29	2	7867
Phase 3		947	750	1030.70	898.80	1	5550
Sponsor Characteristics							
Clinical	Number of drugs in clinical trials	8720	13	70.49	107.93	0	382
Marketed	Number of marketed drugs	8720	3	109.88	194.91	0	929
Discontinued	Number of drugs that have been discontinued	8720	10	83.62	140.71	0	581
Drugs	Total number of drugs developed	8720	48	290.62	452.20	1	1719
Innovativeness	5 year citation weighted patent count	8719	0.77	4.31	6.97	0	83
Project Characteristics							
Indications	Number of diseases that the same compound is being developed to treat	8722	2	3.75	4.33	1	38
Exploration Alliances	Indicator of co-development in product development	8722	0	0.23	0.42	0	1
Exploitation Alliances	Indicator of sales, marketing or manufacturing partnerships in product development	8722	0	0.04	0.20	0	1
Licensing agreement	Indicator that rights to develop a technology were obtained through a licensing agreement	8722	0	0.09	0.29	0	1
# Companies involved	Number of companies involved in development	8722	1	1.60	0.86	1	9
Technological Diversity	Total number of sub-fields partner firms operate in	3622	3	4.94	4.53	0	33
NPD Complementarity	Degree of difference in NPD expertise between partner firms and sponsor firm	3622	0.89	0.90	0.50	0	2.65

4.2. Methods

I estimate the effectiveness of the various NPD risk mitigation strategies previously described to advance pharmaceutical products through clinical trials using a shared frailty Weibull survival regression analysis (Cleves et al., 2016). Survival analysis is necessary to obtain consistent and efficient estimates of the variables because many of the projects in the sample have not made it to the next phase of research or have been discontinued and are therefore censored (Hanagal, 2006). I test the hypotheses in each of the three phases of clinical trials. Each is estimated separately to determine the effectiveness of the mitigation strategies throughout the development process.

The duration of time it takes for each stage is the dependent variable and modeled as a log linear function of the covariates according to equation (1).

$$\log(t_j) = \mathbf{x_j}\boldsymbol{\beta} + z_j \tag{1}$$

Where $\mathbf{x}_j$ is a vector of covariates and $\boldsymbol{\beta}$ is their corresponding vector of regression coefficients. The error term, z_j, is modeled with a Weibull probability distribution. I utilize the Weibull model because it allows for hazard rates to increase or decrease exponentially with time rather than the more common Cox regression which assumes that the hazard function is constant. This assumption is likely not valid in the case of pharmaceutical drugs due to the change in technology and policy over time. The Weibull hazard function takes the form:

$$h(t) = p\lambda_j t_j^{p-1} \tag{2}$$

$$\lambda_j = \mathrm{e}^{-p\mathbf{x}_j\boldsymbol{\beta}} \tag{3}$$

where p is the estimated shape parameter; the hazard rate, represented by equation (2) is increasing if p is greater than 1 and decreasing if p is less than one. The scale parameter displayed in equation (3), λ_j, allows for estimation of the impact of covariates on the hazard rate.

In addition, I account for potential correlation in error terms using the gamma shared frailty model. The frailty was defined to be shared by year to account for differences in policy, technology and economic health over time.

5. Results

I present the results in Tables 2 and 3. The results are presented in a hierarchical order, with the controls in model 1, the addition of main effects in model 2, and the interaction effects in model 3. Early and late phases of clinical trials were estimated separately to determine the effectiveness of alliances at the two stages in the development process. Phase I and II were combined because they were hypothesized in the same direction and many products are allowed to bypass phase I if the same compound has passed the safety requirements for a different drug. A dummy variable accounting for the differences in failure rate of drugs in the first phase was included in the early regression analyses. Combining them also aligns with the theoretical motivation of exploration versus exploitation and has precedence in literature in the pharmaceutical industry (Urbig et al., 2013). Across the phases, each of the control variables exhibits a similar pattern of effect sizes and significance levels. Innovativeness was not significantly related to failure likelihood. An increase in number of diseases that a drug is being developed for reduces the risk of drug failure, confirming results from past research (DiMasi, 2013). Size as measured by the total number of products in the company's pipeline is positive and significant, indicating an increased likelihood of failure for larger companies. An increase in the number of companies involved in development reduces failure likelihood, supporting the general notion that a greater knowledge base reduces risk. In each model, the Weibull shape parameter is greater than 1, indicating that the hazard rate is increasing as the project remains in development at a decreasing rate.

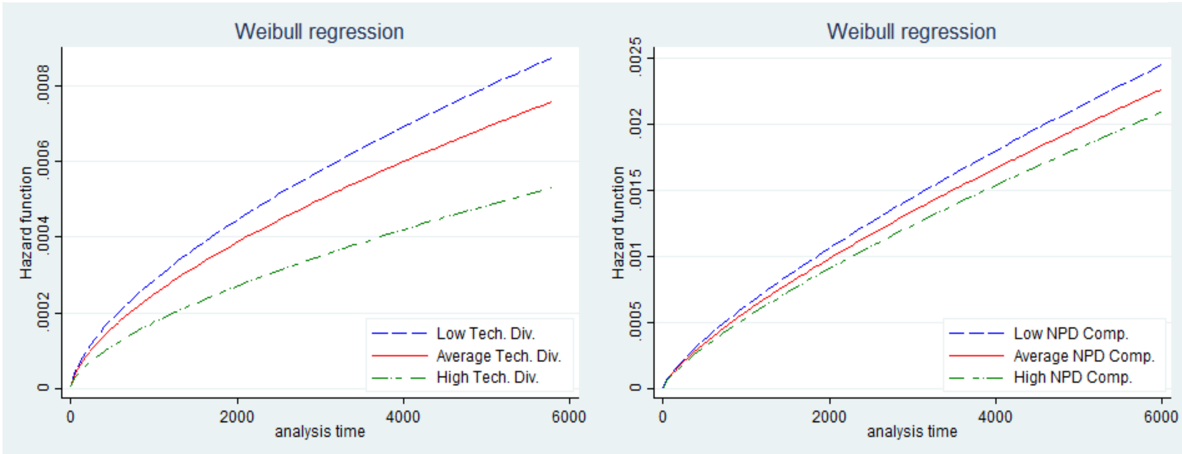
Table 2. Weibull survival regression model results for Phase 1 & 2 clinical trials

Early	Model 1			Model 2			Model 3		
	β		se	β		se	β		se
Intercept	-12.970	***	(0.200)	-13.111	***	(0.201)	-13.097	***	(0.201)
Phase 1	0.171	***	(0.037)	0.169	***	(0.037)	0.167	***	(0.037)
Indications	-0.014	***	(0.004)	-0.014	***	(0.004)	-0.014	***	(0.004)
Size	0.018	***	(0.003)	0.018	***	(0.003)	0.018	***	(0.003)
Innovativeness	0.025		(0.022)	0.022		(0.022)	0.022		(0.022)
Co.	-0.151	***	(0.019)	-0.107	***	(0.032)	-0.138	***	(0.035)
License	0.065		(0.068)	0.106		(0.074)	0.082		(0.075)
Exploration				0.079		(0.057)	0.270	**	(0.092)
Exploitation				-0.173	†	(0.099)	-0.362	**	(0.135)
Tech. Div.				-0.012	†	(0.007)	-0.009		(0.007)
P-Size				0.007		(0.008)	0.001		(0.008)
NPD Comp.				0.002		(0.021)	0.030		(0.036)
AP. Innovativeness				-0.094	*	(0.042)	-0.031		(0.051)
Exploitation Interactions									
Tech. Div.							0.026		(0.027)
P-Size							0.056		(0.038)
Exploration Interactions									
NPD Comp.							-0.205	*	(0.092)
AP. Innovativeness							-0.047		(0.045)
Weibull shape parameter	1.761			1.762			1.760		
Frailty Parameter	0.566	***	(0.013)	0.566	***	(0.013)	0.567	***	(0.013)
N	7239			7239			7239		
AIC	11927.3			11924.1			11920.8		
Log lik.	-5929.9			-5922.7			-5917.2		

Note: Standard errors in parenthesis. Fixed effects were included as controls in each model for every therapeutic area treated by the drug in development, but are excluded from the table for clarity.

$^{\dagger}p<0.10$, $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$

Figure 2. Moderation effects on Hazard rate for Early Phases (*left)* and Late Phase *(right)*



Turning to the effect of the covariates of interest, early phase results are presented in Table 2. Model 2 displays the main effects of the different types of alliances. The coefficient of exploration alliance is not significant, rejecting the first hypothesis (1a). Supporting hypotheses 2a, exploitation alliances are moderately significantly associated with a 16.2% (β=-0.177, $p<0.10$) reduction in the failure likelihood. When adding the interaction terms, the significance of exploitation alliances increases along with the effect size (β =-0.376, $p<0.01$), while the main effect of exploration alliances become significant (β =.278, $p<0.01$). However, the direction of this significant main effect is counter to hypothesis 1a. In model 3, there is only one significant interaction between exploration alliances and NPD complementarity (β =-0.209, $p<0.05$). Comparing two exploratory alliances while holding all other variables constant, an increase of one unit in NPD complementarity yields an 18.9% reduction in failure likelihood. I find here that the impact of exploratory alliances on product development varies depending on the differential expertise of the partners. Specifically, exploratory alliances by themselves result in increased product failures, but when partner expertise differential is high, exploratory alliances seem to reduce product failures. While these results display an inverse relationship than the main effect posited in hypotheses 1a, it supports the moderating hypothesis 3b and does not support hypotheses 3a.

Table 3. Weibull survival regression model results for Phase 3 clinical trials

Late	Model 1		Model 2		Model 3	
	β	se	β	se	β	se
Intercept	-12.280 ***	(0.491)	-12.400 ***	(0.494)	-12.380 ***	(0.497)
Indications	-0.026 *	(0.011)	-0.022 *	(0.010)	-0.022 *	(0.011)
Size	0.007	(0.009)	0.013	(0.009)	0.012	(0.009)
Innovativeness	-0.075	(0.064)	-0.060	(0.068)	-0.052	(0.070)
Co.	-0.192 ***	(0.046)	-0.170 *	(0.079)	-0.228 **	(0.086)
License	0.530 **	(0.181)	0.724 ***	(0.218)	0.694 **	(0.227)
Exploration			0.284	(0.173)	0.472 †	(0.249)
Exploitation			-0.649 ***	(0.177)	-0.378	(0.263)
Tech. Div.			0.011	(0.019)	0.033	(0.021)
P-Size			0.013	(0.024)	0.004	(0.027)
NPD Comp.			-0.030	(0.047)	0.026	(0.078)
AP Innovativeness			-0.294 **	(0.114)	-0.249 †	(0.147)
Exploitation Interactions						
Tech. Div.					-0.100 *	(0.051)
P-Size					0.009	(0.057)
Exploration Interactions						
NPD Comp.					-0.195	(0.242)
AP Innovativeness					-0.100	(0.098)
Weibull shape parameter	1.613		1.634		1.639	
Frailty Parameter	0.478 ***	(0.035)	0.491 ***	(0.035)	0.494 ***	(0.035)
N	1507		1507		1507	
AIC	2040.1		2026.0		2028.0	
Log lik.	-997.0		-984.0		-981.0	

Note: Standard errors in parenthesis. Fixed effects were included as controls in each model for every therapeutic area treated by the drug in development, but are excluded from the table for clarity. †p<0.10, *p<0.05, **p<0.01, ***p<0.001

In the final phase of clinical trials shown in Table 3, the main effects of exploitation alliances are significant and negative, supporting hypothesis 2b (β =-0.649, p<0.001). When adding the moderating alliance variables in model 3, the main effect of exploitation becomes insignificant, while the main effect of exploration alliances becomes moderately significant and positive (β =0.472, p<0.10). The moderating effect of technological diversity is significant and negative (β =-0.100, p<0.05). The moderating effect when two exploitation alliances are compared while holding all other variables constant yields a 9.5% reduction in failure rate with an increase of one unit of technological diversity. This result provides support for hypothesis 4a.

Table 4. Summary of Hypotheses

Hypotheses	**Variable**	**Phase**	***p*-value (<)**	**Direction**	**Supported**
1a	Exploration Alliances	I-II	0.01	+	N
1b		III	0.10	+	N
2a	Exploitation Alliances	I-II	0.01	-	Y
2b		III	n.s.	-	N
3a	Partner Innovativeness	I,II,III	n.s.	-	N
3b	NPD complementarity	I,II,III	0.05	-	Y
4a	Partner Size	I,II,III	n.s.	+	N
4b	Technological diversity	I,II,III	0.05	-	Y

5.1. Robustness

While a Weibull distribution with shared frailty was used to estimate the model, there are other models and distributions that could have been applied. First, I assessed the impact of different distributions on the results. The full model (model 3 in each phase) was estimated using the exponential, gamma, log-normal, Gompertz, and loglogistic distributions. The estimates from each model were consistent regardless of distribution used. AIC values from each model were also compared to ensure the best distribution was selected. The AIC value for the Weibull was slightly higher than the log-normal, but not enough to override the theoretical justification for utilizing Weibull distribution.

Cox regression was also performed and showed remarkably similar results. One of the primary assumptions of Cox regression is that the covariates have proportional hazards. This assumption was tested by interacting each covariate with the survival time and including it in the original regression (Cleves, 2008). Each interaction was insignificant, supporting the assumption of proportional hazards. Outliers were detected by obtaining the Nelson-Aalen cumulative hazard rate for each regression and plotting it against the residuals from the model. Dropping outliers and rerunning the model did not significantly change the results for each model. To assess the accuracy of functional form, martingale residuals were visually inspected. No significant linear trend or asymmetry was observed.

5.1.1. Endogeneity

While it is difficult to know with certainty if a project is going to succeed, APs will pursue collaboration on projects they expect to succeed. Since time to failure is the dependent variable in the model, this may lead to a sample selection issue that can result in overestimation (Heckman, 1979). Although, I do not expect this to be a serious problem because all projects are pursed with the expectation they may succeed regardless if alliance partners are involved or not. To minimize the concern of selection bias, I use a two-step estimation procedure to ensure that endogeneity is not biasing the results. APs may decide to become involved in a project because of the attributes of the company they are partnering with and the characteristics of the drug in development. Thus, an indicator of alliance formation is regressed in the first stage on the sponsor company's innovativeness and its size, along with the project characteristics: total number of companies involved in the project, the therapeutic area, and the molecule type. The inverse mills ratio was estimated from the first stage and included as a control in the original model specification. The mills ratio is insignificant and the results remain consistent. Summary of robustness results are presented in the appendix.

6. Conclusion

Simply engaging in exploration alliances in clinical trials is not enough to reduce risk, and unless alliance partners are chosen carefully based on the capabilities they possess, may increase project failure. The two early development stages, phase I & II, require partners with unique expertise in developing products to reduce risk. A greater differential in NPD complementarity reduces the rate of failure, but at low levels there is an increase in risk. This result suggests that organizational learning from exploratory alliances is accomplished more effectively with alliance partners who have a different perspective on the development process. This interpretation is important because it suggests that the impact alliances can have is much stronger than suggested in past literature. Not only can they improve successes, they also reduce failures which further strengthens the motivation to engage in strategic alliances. It also indicates that the most fertile combination of knowledge is from diverse and intimate knowledge of processes. As drug development progresses to phase III, exploration alliances do not reduce the risk of project failure, even with alliance partners that have high NPD complementarity.

In the final phase, technological diversity of exploitation alliances becomes important in reducing the risk of project failure. This further supports the importance that knowledge diversity plays in cultivating risk mitigation while demonstrating how the type of diversity that should be sought is dependent on the stage of development. Differences in knowledge domains gained through expertise in different industry subfields can be combined to minimize risk. Without considering the attributes of exploitation partners, exploitation alliances reduce NPD risk in and of themselves. When technological diversity of the exploitation alliance partners is included, greater diversity is shown to be the primary factor driving the risk reducing impact of the alliances.

Exploitation alliances not only reduce risk in the last phase of NPD, but also in earlier phases as well. This result highlights the importance of understanding how alliance partners sought for exploitation may have a significant effect on the development of a project rather than just on the final characteristics of the product. This may be a result of the reality of the drug development process. When the entire product development stage is considered, clinical trials consist of the latter half of development. Thus, even in phase I and II, exploitation can benefit development processes. Additionally, alliance formation is a process that not only takes time, but also must be initiated before the product is ready to be exploited. The experiential knowledge of exploitation partners may be leveraged during the formation process to reduce the risk of the product failing before it reaches the point that exploitation APs take the lead in marketing or producing the product.

Despite the extensive application and research on the impact APs have on innovation outcomes, their role in risk management has been almost ignored. Considering how widely alliances are applied to mitigate project level risks, surprisingly little is known about their effectiveness in reducing risk beyond simply sharing cost. The results presented provide several interesting and useful insights that take one step toward a more comprehensive understanding of the role of alliance in risk management. When seeking alliance partners, managers should consider alliance partners for both their capabilities as innovators and as joint risk managers. The risk reducing effect of alliances was also shown to vary by the type of alliance and the attributes of alliance partners in relation to one's one throughout the drug development process.

By understanding the role that alliances have in risk management, the valuation and selection of APs may be improved. I showed that the characteristics of APs in relation to the sponsor company are a key factor in determining if and to what extend APs reduce risk. Considering the astronomical cost of drug development, even small improvements in failure rate can have large consequences. This study provides an alternative perspective from the most common risk management tools used in NPD which are borrowed from financial analysis (Doctor et al., 2001) and include net present value (NPV), decision trees, discounted cash flow, and Monte Carlo simulation (Kleczyk, 2008). All of these methods are used to measure risk, not mitigate it. Other scholars have also stressed the importance of risk mitigation for NPD in biotechnology

(Vanderbyl and Kobelak, 2008), but none have quantified the impact mitigation strategies have. This study contributes to the project risk management literature by motivating and quantifying the impact alliances have to mitigate risk.

It is imperative to develop a better understanding of project risk and actions that can be taken to reduce them. Pharmaceutical companies must mitigate the risk of project failure which requires an understanding of the effectiveness of the strategies they employ. The complexity of this decision making process coupled with the fact that only 1% of compounds make it through the NPD process, results in imprecise methods for determining which path to take (Gino and Pisano, 2008). Many trends in pharmaceutical strategy can be seen from a risk management perspective, including alliance formation. My findings suggest that there is not a pure temporal separation between the influence of exploration and exploitation alliances as risk mitigation strategies. Product development is a continuous process and mitigating risk requires preemptive action. Both types of alliance allow organizations to leverage the experiential knowledge of AP. However, alliance partner attributes specific to the type of alliance sought need to be considered when forming alliance.

Chapter 3 - The Impact of Culture on Supply Chain Risk Perception and Mitigation

1. Introduction

Making investment decisions on mitigating supply chain risk is a complicated process. Supply chain managers are faced with many sources of risk and have several ways to mitigate them. For instance, supplier quality control, equipment malfunction, and demand uncertainty each threaten the continuity of a supply chain, but require different types of mitigation strategies to combat them. Additionally, these risks are interdependent and firms must rely on supply chain partners whom often cross international borders. Effectively mitigating supply chain risk requires coordination (Kleindorfer and Saad, 2005), but past research has shown that coordination of global operations can be challenging (Prater and Ghosh, 2006), especially since cultural and geographical differences may impact the type of operational routines used by firms (Kull and Wacker, 2010). This is particularly relevant in supply chain risk management because of the global interconnectedness of supply chains and vast differences between cultures that may influence the adoption of risk mitigation strategies. Research has shown that several differences exist between countries that may systematically influence how risks are mitigated (Lytle et al., 1995). To ensure effective risk mitigation, these cultural differences must be acknowledged to ensure that interfirm relationships support risk mitigation. Despite the known cultural differences between countries (Hofstede, 2001) and the reliance on international supply partners for building a resilient supply chain (Pettit et al., 2010), the supply chain risk management literature has yet to study these cultural implications. This chapter investigates how culture influences the perception of supply chain risk and the types of strategies used to mitigate them. I do this in multiple stages. First, I develop measures of risk mitigation across the supply chain, test whether these measures are invariant, and finally, examine the how these measures differ across countries using cross sectional data.

Risk mitigation is one of the key steps of the risk management process and involves the preemptive implementation of strategies to either reduce the probability and/or impact of a disruption (Kern et al., 2012). Culture influences the behavior of a firm's employees (Schein, 1985), which likely results in different in risk mitigation patterns. Making decisions involving risk is particularly exposed to being influenced by culture, requiring better explication of how cultural differences influence the perception of risk. Hofstede's (1980a, 1980b, 1984, 2001) seminal work on culture is widely used and identifies six primary dimensions that vary between cultures: Power Distance, Individualism-Collectivism, Masculinity, Uncertainty Avoidance, Long Term Orientation, and Indulgence.

Of the cultural dimensions, Power Distance, Uncertainty Avoidance, Individualism, Long Term Orientation are directly related to how decisions are reached on mitigating risk. Power distance is the distance between subordinates and their bosses in their ability to make decisions (Hofstede, 1984). When power distance is high, there is a lack in autonomy to make risk mitigation decisions and the strength of voice that subordinates may exhibit (Brockner et al., 2001). Since much of the tacit knowledge relevant for optimizing risk management is contained in employees involved in everyday operations whom have low power, accounting for power distance in designing strategies may be important. Uncertainty avoidance refers to the level of comfort individuals have in making decisions with high degrees of uncertainty. Since adopting risk mitigation strategies is highly uncertain, countries with high uncertainty avoidance may be less flexible in the choices they make since they are more likely to abide by strict rules of conduct (Hofstede, 1980, 2001). The degree to which people prefer to work individually or within a group is referred to as individualism (or equivalently its inverse, collectivism). Since employees act as agents for a firm, higher levels of individualism (lower degree of collectivism) may result in the adoption of strategies that may take more of an individual's opinions or experiences into account. Finally, long term orientation refers to the length of time horizon that individuals prefer for planning. Thus, people in a high long term orientation society highly value planning and are more likely to accept short-term losses (Ashkanasy et al., 2004). This may also influence risk mitigation decisions because they are preemptive and may require a long-term view. Consistent with this idea, Chopra and Sodhi (2004) found that managers focus on low impact reoccurring events rather than long-term disruptive events. Despite the importance of cultural dimensions on risk mitigation, studies in the current literature have not examined this aspect.

Risk mitigation is undoubtedly a vital component of a high performance supply chain, but the extent and type of risk mitigation strategies to implement is not as clear because of the many ways in which risk can be mitigated. Despite the variety in methods for mitigating risk, they all function by providing a firm with slack. Cyert and March (1963) asserted the importance of slack in determining organizational behavior when they proposed a behavior theory of the firm. Slack is "…that cushion of actual or potential resources which allows an organization to adapt successfully to internal pressures for change in policy, as well as to initiate changes in strategy with respect to the external environment" (Bourgeois, 1981, p. 30). Further, organizational perceptions of slack can also be influenced by culture, and consequently influence organizational response (Bansal, 2003). This suggests that culture is an important attribute to consider in the context of risk management. Slack is not unidimensional and differs in its availability for use. Firms keep slack in different ways to combat uncertainty. For instance, unabsorbed slack is kept to be used immediately while absorbed slack can be appropriated when necessary (Tan and Peng, 2003). While several authors have studied the importance of slack for innovation (Nohria and Gulati, 1996) or financial performance (Bromiley, 1991), I focus on developing a more thorough understanding of the role slack plays in mitigating supply chain risk, and test for cultural differences in perceptions of the slack.

Focusing on slack, two specific types have been proposed in the literature that are relevant for risk mitigation: absorbed or unabsorbed (Sharfman, 1988). Absorbed slack is derived from resources already committed to current operations. Managers may have less discretion in modifying this form of slack. In contrast, unabsorbed slack is derived from resources that are yet uncommitted (Lee and Wu, 2015). Within the domain of supply chain risk, I relate these two types of slacks to flexibility and redundancy, two common supply chain risk mitigation strategies. I argue that the theory of slack provides a consistent basis for categorizing risk mitigation practices and a taxonomy based on the buffering mechanisms of these strategies. There are many different strategies that managers can use to mitigate supply chain risks which have the characteristics of absorbed or unabsorbed slack. Further, managerial perceptions about these can differ based on their cultural vantage points and business practices (Newman and Nollen, 1996).

Focusing on risk mitigation strategies, the supply chain literature has argued that flexibility and redundancy are important primary strategies for mitigating risk. For example, Chopra and Sodhi (2004) argue that flexibility and redundancy are among the most fundamental risk reduction strategies of the eight proposed. Similarly, Sheffi and Rice (2005, p. 41) note: “An organization’s ability to recover from disruptions quickly can be improved by building redundancy and flexibility into the supply chain.” Sodhi and Tang (2012) describe flexibility and redundancy as two of three risk mitigation categories. While other studies have developed alternative classifications of risk mitigation strategies based on their observations (Johnson et al., 2013; Scholten et al., 2014), flexibility and redundancy are reoccurring classifications used across the literature. Finally, both flexibility and redundancy, as I will discuss, are measures that can be anchored on the foundations of slack. Accordingly, I focus on these two dimensions in this study.

Finally, it is important to recognize that supply chains are not monolithic entities. Rather, supply chains are composed of different parts in the overall firm's value chain – namely supply, process and demand. Both flexibility and redundancy are implemented across the different stages of the supply chain and their implementation in individual stages can have an influence on the overall chain. It is likely that managerial approach to managing flexibility and redundancy are culturally distinct in each of these stages. In studying cultural differences, and developing measures for supply chain risk, this study focuses on better explicating these differences across the overall supply chain.

Overall this study makes several important contributions to the literature. First, I develop a measure of redundancy and expands scales of flexibility to the domain of risk with the consideration that these strategies differ across the value chain. Measures that have already been developed for supply chain risk have not yet captured these elements of mitigation and are usually operationalized at a higher or lower level of analysis; refer to Table 5. Secondly, I apply the theory of slack to supply chain risk mitigation strategies so that the different typologies proposed in the literature can be related to one another by their theoretical mechanisms. Lastly, I uncover the differences culture makes in risk perception and mitigation. I achieve this by creating a survey instrument, collecting data with it in three countries, and testing the invariance between the scales.

2. Theoretical Development

The literature on supply chain risk management is continuing to grow and yield valuable insight for managers and researchers. However, there are still several gaps in the literature, including a dearth of empirical studies (Sodhi et al., 2012). I contribute to filling that gap by developing measures of redundancy and expanding the context of flexibility. The following section builds on past research to create a theoretical understanding of the differences between the two types of strategy based on organizational theory of slack.

2.1. Slack

The forms slack can take include financial reserves (George, 2005) excess labor (Steele and Papke-Shields, 1993), or any other resources that are in excess of what is required for business operations. In reality, maintaining zero slack is often impossible and the challenge for managers is not deciding to have slack or not, but determining how much slack is optimal. According to lean manufacturing principles, slack is a waste and can lead to inefficient and poor performance (Inman and Mehra, 1993). On the other hand, slack is necessary to buffer against variability in lead times, production delays, uncertain demand, as well as other environmental fluctuations. Therefore, determining the appropriate types and levels of slack is necessary for managing supply chain risks (Chopra and Sodhi, 2004; Kleindorfer and Saad, 2005).

The supply chain risk management literature describes many different practices that are used to mitigate supply chain disruptions which have the properties of slack. For instance, extra capacity (Bourland and Yano, 1994) and inventory (Hendricks et al., 2009) are both well-known supply chain risk mitigation strategies and have been studied under the lens of slack resources.

These types of slack have been termed operational and differ in accessibility from more general financial measures of slack (Bourgeois 1981). Bourgeois (1981) argued that operational slack is embedded in production, and therefore less available than more discretionary organizational slack, such as financial reserves. Considering the variety of operational practices used for mitigating supply chain risks, it would be incorrect to assume that all forms of operational slack have the same degree of discretion. Huang and Chen (2010) show that operational slack can be more easily deployed than past research would suggest. Rather than subsuming all operational practices into a broad classification of operational slack, I seek to understand two types of slack I define as redundancy and flexibility. These two types of operational slack differ by the mechanism in which they buffer against shocks and their availability for deployment.

2.1.1. Available Slack

Redundancies are a form of slack by definition. Operations managers use redundancy to ensure resilience to disruptions both within and external to their firm. The function of redundancies is best understood from a systems or network perspective. In graph theory, scale free networks have been shown to be resistant to random attacks to the network (Albert and Barabasi, 2002). This phenomenon can be generalized to supply chain networks since they have been shown to have the characteristics of scale free networks (Sun and Wu, 2005). Resistance in graph theory refers to the structure of the network maintaining its structural characteristics after disruptions occur in the form of ties or nodes being removed from the network. This resilience is largely a result of redundancy. Similar to when a supplier were to be removed from a supply chain, when a node (firm) is removed, all of its vertices (connections) are destroyed as well. However, the connectivity of the network is maintained as a result of a substantial number of redundant vertices linking the network together.

From a systems engineering perspective, redundancies are a key parameter in determining the reliability of a system. Supply chains can be viewed as systems since they have a similar structure to mixed systems that contain both a series and parallel structure for the movement of goods and information. Optimization techniques can be implemented to determine the necessary number of redundancies to achieve certain levels of reliability in systems (e.g., Chern, 1992; Ghare and Taylor, 1969). Similarly to supply chains, redundancies also have a cost associated with them which needs to be considered when determining optimal levels of redundancy. By understanding how redundancies operate in systems and networks, it is apparent that they are deployed immediately in the event of a disruption since they replace the resource they are a duplicate of. This basic function is the same for improving business continuity in supply chains. Therefore, the classic assumption that all operational slack is unavailable may be invalid and limit the understanding of slack.

Most studies in supply chain management focuses on only one type of redundancy, primarily in manufacturing. For instance, Hendricks (1992) sought to determine optimal buffer allocation in serial production lines to maximize throughput and minimize variability. Other examples include buffer capacity (e.g., Enginalar et al., 2002) and inventory stocking levels (e.g., Ha, 1997). Similar to research on internal redundancies used for manufacturing, most research on upstream or downstream risk mitigation strategies only investigates a single practice. For instance, Yu et al. (2009) model single versus dual sourcing on supply chain performance with disruptions. They argue that single sourcing has advantages, such as cost and relational efficiencies, but can be risky in the case of a major disruption and show that the choice of sourcing decision depends on magnitude of disruption probability. Bartezzaghi and Verganti (1995) explore the risk mitigation benefits of over-planning under demand uncertainty by constantly adjusting slack. These studies share a common theme, a focus on cost reduction rather than risk minimization. I build on these studies by developing a construct of redundancies that are kept to minimize risk.

2.1.2. Unavailable Slack

Ironically, flexibility has been used in a wide variety of settings, representing many different business practices. For the purpose of this study, I focus on supply chain flexibility used to mitigate risk which incorporates internal, upstream, and downstream practices. Slack can also be thought of in terms of flexibility. Levinthal (1997) described the mechanism of slack in navigating rugged landscapes by the ability to adapt. Adaptation is the fundamental property of strategies classified as flexible that afford risk reduction. Based on this description, flexibility provides the potential to adapt to change so is a form of slack, but since it functions by adaptation, it is less discretionary.

Studies testing the influence of flexibility on supply chain risk have been few, and primarily analytical. One exception was a study by Lee and Makhija (2009) that showed the effect of strategic flexibility, as measured by international investments, on firm value during an economic crisis. Tang and Tomlin (2008) show the value of flexibility in mitigating supply chain risks using five stylized models of multiple suppliers, flexible supply contracts, flexible manufacturing processes, postponement, and responsive pricing. They concluded that relatively low levels of flexibility significantly reduce risk and that there are decreasing returns to scale for investments in flexibility. While flexibility has been studied extensively, it has been done so primarily in the area of manufacturing flexibility. Slack (1983) provided a foundation for the literature to build from through an examination of flexibility as a manufacturing objective that provides completive advantage. Upton (1995) revisited manufacturing flexibility by highlighting the many challenges managers face in implementing flexibility. Although, a broader perspective on flexibility needs to be adopted to account for all of the risks firms are exposed to. Swafford et al. (2006) addressed this issue when they developed measures for flexibility, separating flexibility into three functional areas: procurement/sourcing, manufacturing, and distribution/logistics.

Sharfman (1988) clarified the definition of slack by distinguishing it from waste and other buffers. The importance of this distinction is that flexibility must be purposely created for mitigating risk. Consider two pieces of manufacturing machinery, one can only produce one product, while the other can produce that same product as well as other products when necessary. The equipment that can produce multiple products fits the classification as flexible, but only if the additional function is purposely reserved to buffer risk. Although, flexibility is not purely an excess resource which will affect how easily it can be deployed. Continuing with the previous example, a piece of manufacturing equipment requires time to change over to producing a new product and cannot perform its primary role when being applied to mitigate risk. The additional time and opportunity cost render flexibility less discretionary than redundancy as a form of slack. Therefore, it can be thought of as a potential or unavailable slack. In one study that compared these two types of slacks, Talluri et al. (2013) show in a simulation that flexibility is a more efficient strategy to adopt than redundancy. The reason for this finding is that despite the slack being less discretionary, is still functions as a buffer without sitting idle as available slack does.

2.2. Supply Chain Risk

Reviewing the literature exposes another critical distinction that is missing in studies on slack: the source of uncertainty that is buffered. Previous literature on slack has predominantly investigated the benefits of slack on general uncertainty, without matching the types of slack to specific sources of uncertainty. A few exceptions do exist. For instance, Caputo (1996) discussed the difference buffers play in internal and external uncertainty through illustrative examples. Cheng and Kesner (1997) went further to hypothesize and test the different roles internal and external slack play in resource allocation. However, the effectiveness of slack under different sources remains underdeveloped, especially when focusing on supply chain risk.

The classification of risk in supply chains varies substantially in the literature. Based on a review on the literature, Ho et al. (2015) divide supply chain risk into Macro and Micro risks. This classification aligns closely with those that other scholars have proposed, such as catastrophic/operational (Sodhi et al., 2012) and disruption /operational (Tang, 2006). Ho et al. (2015) further divide micro risks into four categories: supply, manufacturing, demand, and infrastructural. Christopher and Peck (2004) categorize the sources of supply chain risk similarly into five elements: supply, process, control, demand, and environmental. Environmental risk refers to the inherent risk all firms face, while two of these risks are external to the firm, the other two internal. Internally, control and process risks are those that threaten the sequence of value-adding steps undertaken by the firm and procedures that govern them. Demand and supply risks are the two external sources of risk that threaten product, material, or information flows either down or upstream of the firm. External sources of risk are harder to detect (Christopher and Peck, 2004), and as a consequence harder to dedicate the appropriate level of slack towards. Rather than risk, Bode and Wagner (2015) show that three types of complexity, horizontal, vertical and spatial, are related to an increase in supply chain disruptions. These same authors also studied the antecedents of three types of supply chain risk, demand-side, supply-side, and catastrophic (Wagner and Bode, 2006). Other types of risk that threaten the continuity of supply chains have been labeled infrastructural and include transportation, information technologies, and financial systems (Ho et al., 2015). In proceeding, I focus the study on micro supply chain risks and classify them as internal (process, manufacturing and control) and external risk (supply and demand).

2.3. Cultural Influences on Risk Mitigation

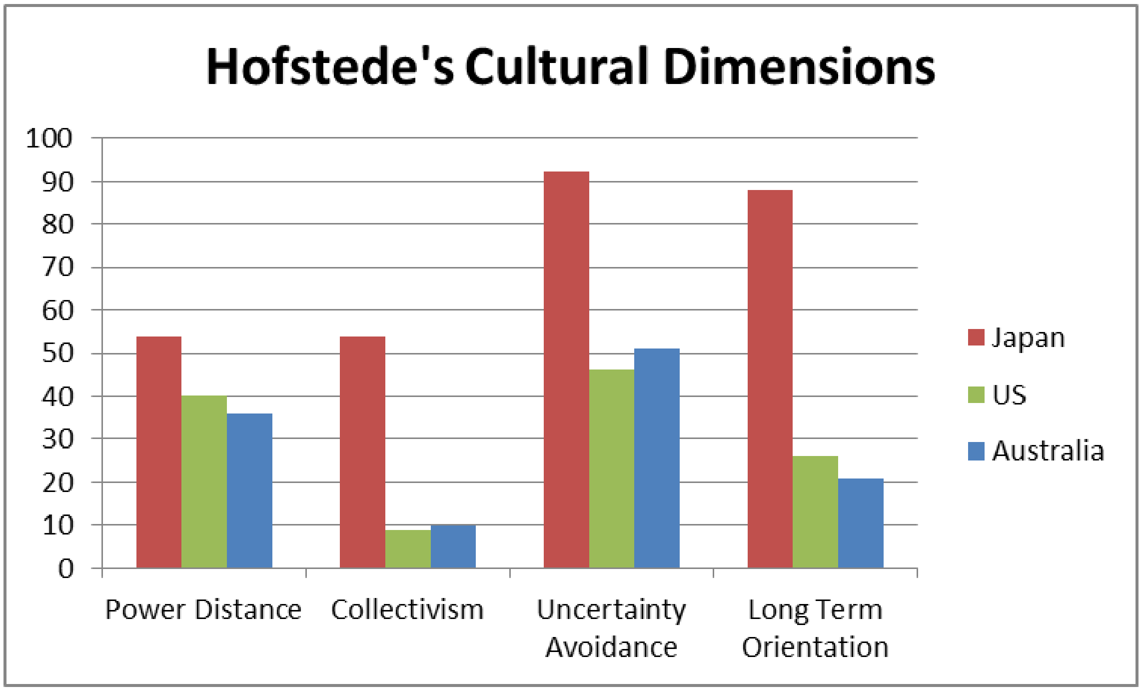
Deciding which type of slack to apply to mitigate internal or external risk may be a function of culture as well as organizational requirements. One of the main challenges in measuring supply chain risk is that context influences risk perceptions between organizations (Desai, 2008). The risk management literature suggests that buffers are chosen based on the exposure to risk, but has not shown how culture influences the allocation of these buffers.

The main difficulty in optimally mitigating any risk is that they are uncertain. Thus, effectively mitigating risk requires utilizing as much information as possible. In countries where power distance is high, managers make decisions and their subordinates do not conflict with their decision. In countries with low power distance, managers' decisions are more likely to be challenged if their decisions do not align with their subordinates. While disagreement can lead to conflict, conflict may be a source for discourse that may lead to better decisions (Amason, 1996). Based on the impact power distance may have on decision making, I expect differences in risk mitigation adoption between countries that have varying levels of power distance.

Collectivism "…requires that individuals sacrifice themselves for the alleged interests of the collective" (Realo et al. 2008, p.448). Thus, collectivism may influence the choice of slack applied to mitigate risk because of the inherent desire to ensure the safety of the group. Power et al. (2010) argue that collectivism influences operational goal orientation and that high collectivism is associated with greater goal congruence. Therefore, collective goals such as mitigating firm risk are a priority over individual achievements that may lead to suboptimal decision (Ramamoorthy et al., 2007). In combination with power distance, a focus on collective goals suggests the power distance enhances collectivism so that managers will engage with their subordinates in order to achieve goal congruence. This may lead to a greater application of long term strategies that are best suited to mitigate risk comprehensively rather than addressing minor reoccurring problems. Potential slack requires greater investment and planning than available slack, consistent with the goal of achieving the greatest level of risk mitigation in the long term. Additionally, flexibility, often associated with potential slack, has been shown to be more effective at mitigating risk than redundancy, another term for available slack (Talluri et al. 2013).

Two other dimensions of Hofstede's cultural thesis that are highly relevant for this study are uncertainty avoidance and long term orientation. Uncertainty Avoidance is "…the reliance on norms and procedures to alleviate unpredictability' (Kull and Wacher 2010, p. 228). Relying on norms and procedures is associated with a greater application of fact-based decision-making and scientific methods (Naor et al., 2010). However, Weber and Hsee (1998) show that the perception of risk was the key difference in risk behavior between cultures. Thus, I expect countries that are high in these two will have a higher degree of perceived risk. Western countries have lower uncertainty avoidance and long term orientation scores than do Confucian Asian countries. Developing a survey to study risk management should cover a broad international region since the scope of supply chains is worldwide. Accounting for these potential cultural influences are necessary when designing a survey based on the previous discussion. In the following sections, I seek to uncover how these differences influence measuring risk and mitigation strategies.

Figure 3. Cultural Differences



3. Methods

To develop the measures, I collected data using a cross-sectional survey instrument. The survey was administered in three first world countries: the United States of America, Australia, and Japan. These countries were chosen to provide a strong contrast in cultural values while providing as close to a geographical control as possible. The USA and Australia have similar cultural dimensions, both with a stark contrast to Japan. Meanwhile, Australia and Japan are located in the south pacific across the Pacific Ocean from the USA. Supply chain strategies and configuration may be a result of location as well as culture. Since I am trying to investigate the role culture plays in risk perception and mitigation, I chose the closest country to Japan that has similar cultural dimensions as the USA in order to provide the best control group available. I created the survey instrument by following standard development techniques (Churchill Jr, 1979; Dillman, 2006). The survey was carefully crafted to ensure high quality responses by minimizing cognitive burden and maximizing interest in the survey through question ordering. The survey was pretested by several academics and practitioners before administration, resulting in a few minor structural and grammatical adjustments to the instrument. Anonymity was ensured to limit social desirability, and were not given a detailed introduction to the study, limiting response bias. Furthermore, measures were scaled to specific rates of use whenever feasible or anchored to a specific situation to limit variance in measurement due to perception (Doty and Glick, 1998).

Table 5. Risk Measurement Summary

Articles	**Operationalization of risk mitigation**
Wagner and Bode, (2008)	Risk and Risk management
Weiss and Maher, (2009)	Operational Hedging in the Airline industry
Ellis et al., (2010)	Alternative suppliers
Bode et al., (2011)	Supply chain disruption orientation
Blackhurst et al., (2011)	Global Supply Resiliency
Kern et al., (2012)	Multi-item measure of risk mitigation
Wagner and Neshat , (2012)	Risk management, risk planning and supply chain performance
Grotsch et al., (2013)	Organizational characteristics and SCRM pro-activeness
Hoffmann et al., (2013)	Formative measure of SCRM
Ambulkar et al., (2015)	Firm Resilience

Supply chain, procurement, and logistics managers were the target respondents and they were limited to working for manufacturing firms that have experience managing supply chain risks. Third parties were contracted to administer the internet based survey to managers in the US and Australia. I relied on research partnerships to assist in data collection in Japan. Japan Institute of Logistics Systems (JILS) reviewed the survey, and sponsored it by allowing it to be sent to their member base. The survey was translated into Japanese by a professional translator and compared to the English version of the survey by a bilingual expert in supply chain management. In order to ensure compatibility, several minor corrections in terminology and language were necessary after review. Collectively, I received a total of 209 complete high quality responses. The response rates varied by country, but were only available for the USA. The USA survey was sent to a panel of 7280 potential respondents, of which 803 responded (11% response rate). This is comparable to other studies containing respondents with similar job titles. Many different industries are represented, with a median firm age of 1950 in the American sample, 1980 for the Australian sample, and 1915 for the Japanese sample. The majority of the sample respondents, 82.5%, were very experienced, with 10 years of cumulative experience, 24.8% of them being at their current position for that same length of time. Non-response bias was tested by comparing the average size and revenue of the firms in the final sample to those of the non-respondent. Non-response bias was assessed with the USA sample and t-tests for both size and revenue were insignificant (size: p=0.53; revenue: p=0.84); refer to Table 6.

Table 6. Demographic information

Firm characteristics		**N**	**Median**	**Min**	**Max**
Age (Years)	Japan	55	101	1	124
	USA	98	66	1	179
	Australia	44	35	1	115
Risk management program (years)	Japan	46	5	0	25
	USA	101	2	0	50
	Australia	44	5	0	15
Size (employees)	Japan	58	250 to 499	2 to 4	>25,000
	USA	110	5,000 to 9,999	6 to 9	>25,000
	Australia	44	10 to 49	1	>25,000
Sales ($)	Japan	57	1 bill to 10 bill	<50,000	>10 bill
	USA	110	500 mill to 1 bill	<50,000	>10 bill
	Australia	44	2 to 5 mill	<50,000	>10 bill
Respondent characteristics		**N**	**Median**	**Min**	**Max**
Experience in firm	Japan	57	1 to 3 years	< 1 year	1 to 3 years
	USA	109	6 to 10 years	< 1 year	>10 years
	Australia	44	6 to 10 years	< 1 year	>10 years
Total experience	Japan	58	>10 years	1 to 3 years	>10 years
	USA	101	>10 years	1 to 3 years	>10 years
	Australia	44	>10 years	< 1 year	>10 years

3.1. Constructs

Flexibility was measured using a scale developed by Swafford et al. (2006) that included three dimensions of flexibility: procurement, manufacturing, and logistics. I renamed these dimensions in the study as supply, process and demand respectively. This measure was chosen over other similar measures of flexibility because the items consisted of practices that have been considered risk mitigation in past studies and it captures flexibility at each stage along the supply chain. Redundancy was measured by creating a scale that mirrored the one used for flexibility. Items for the redundancy measures were created from practices classified in the literature as redundancy. This led to a list of 16 practices which were subject to pretesting by five graduate students. This led to a reduction of 4 items per stage in the supply chain. Further pretesting of the survey instrument was conducted with both managers and academics to establish face validity and ensure appropriate wording of the items. The feedback from the pretest resulted in the rewording of several items to align with current practices, improvement of clarity, and removal of doubled barreled items; refer to Table 8, 9 & 10 for a full list of measures.

Wagner and Bode’s (2008) measures of risk were used for the study, but adapted to measure both probability and magnitude. Risk is commonly quantified in practice based on the impact and likelihood of an event. Measuring only one dimension, as originally done by Wagner and Bode (2008), would not capture risk as it is defined, potentially limiting the usefulness of the measure. Thus, I collect data on both probability and magnitude for each item and multiply them together to create each measure. All items were measured on a 7-point Likert scale.

Table 7. Summary Statistics

	Items	N	Mean	St.Dev.	a	b	c	d
a) Absorbed Slack	11	211	4.156	1.138	0.893			
b) Unabsorbed Slack	11	211	3.681	1.108	0.747*	0.890		
c) Internal Risk	4	209	10.804	7.614	-0.028	-0.038	0.848	
d) External Risk	7	209	13.126	6.460	0.042	0.015	0.600*	0.897

*Note: Composite reliabilities (CR) on diagonal

3.2. Validity

A measurement model (confirmatory factor analysis, CFA) was created for each of the survey items by mapping them onto their respective latent constructs. Estimation was conducted using maximum likelihood in Stata 14. Since risk and flexibility were adaptations of past measures, I begin validity testing by comparing the CFA results with published statistics. First, comparing the measures of flexibility to Swafford et al.'s (2006) measures shows that each of the measures exhibited better composite reliability (CR) and average variance explained (AVE) than the original; refer to Table 8. This suggests that the survey adequately reproduced the variables of interest. The measure of redundancy did not have a benchmark to compare to, but is above accepted levels for new constructs; refer to Table 9. Since redundancy is a new measure, only items with a factor loading above .5 were retained, leading to the removal of one item from the process stage.

Next, the measures of risk were compared to the original values reported by Wagner and Bode (2006); refer to Table 10. Supply risk displays similar CR and AVE, process risk has slightly higher CR and AVE, and demand risk has slightly lower CR and AVE. The variance in reliability statistics is likely due to the difference in operationalization of the measures. Note, in this study, supply and demand risks are combined into a single construct of external risk and the individual comparisons were conducted for validity purposes only.

The presence of common method bias was tested using the marker variable technique. Richardson et al. (2009) show that the CFA marker variable is the best of the available methods, but still needs to be viewed with caution. The marker variable is a measure of process technology usage within a company and was chosen because the target respondents should have strong knowledge of these types of technologies and the variance in their use should be associated with the products companies produce rather than the risk mitigation strategies adopted or risk exposure. To begin, a CFA was conducted with all of the constructs, including the unconstrained marker variable. The unstandardized path loadings were obtained, and used as constraints in a baseline model along with constraining the correlation between the marker variable and all others to zero. The second model was identical to the baseline, with the addition of paths from the marker latent construct to each item. The third model constrained the paths added in the previous step to be equal. Finally, the correlations between latent constructs from the unconstrained model were added as constraints to the second model. The chi-square difference tests between each stepwise model were statistically significant, suggesting common method bias is present. While this is not definitive proof of common method bias and may be due to the lack of a perfect marker variable (Richardson et al., 2009), I proceed with caution in using the data. Fortunately, rather than relating variables to one another using regression techniques that would pose endogeneity, my research aim only requires I differentiate between groups responses.

Table 8. Comparison of factor loadings and reliability for risk mitigation measures

Risk Mitigation scales and associated items	Risk mitigation λ_i	Swafford et al. (2006) λ_i
Supply Flexibility	**(CR=0.841; AVE=0.571)**	**(CR=0.600; AVE=0.313)**
Extent to which your supplier lead-time can be expedited/changed	0.771	0.560
Extent to which your supplier short-term capacity can be adjusted	0.783	0.870
Extent of flexibility (options) within supplier contracts	0.805	0.300
Extent to which share of supplied components can be reallocated between suppliers	0.655	0.300
Process Flexibility	**(CR=0.835; AVE=0.560)**	**(CR=0.606; AVE=0.342)**
Range of products manufactured by your firms' plants	0.777	0.560
Average number of products that each manufacturing facility can produce	0.847	0.960
Number of product changeovers per manufacturing facility made each month	0.666	0.330
Range of production volumes across which manufacturing can accommodate	0.689	0.160
Demand Flexibility	**(CR=0.913; AVE=0.779)**	**(CR=0.815; AVE=0.493)**
Average number of items handled by each distribution facility	0.942	0.830
Average number of items per order handled by each distribution facility	0.869	0.870
Average number of customers supported by each distribution facility	0.832	0.830
Number of carriers	-	0.360
Number of distribution facilities	-	0.450

Table 9. Factor loadings and reliability for risk mitigation measures

Risk Mitigation scales and associated items	Risk mitigation λ_i
Supply Redundancy	**(CR=0.760; AVE=0.448)**
Priority in stocking inventory from suppliers	0.722
Amount of capacity reserved by your suppliers in case of changes in requirements	0.731
Number of alternative/backup suppliers selected on a per component basis	0.617
Suppliers' ability to produce components not currently sourced from them	0.596
Process Redundancy	**(CR=0.677; AVE=0.414)**
Amount of capacity reserved in case of sudden changes in demand	0.731
Average number of manufacturing plants that can produce each product	0.571
Amount of equipment stored in each plant to produce components not currently produced in that plant	0.617
Demand Redundancy	**(CR=0.771; AVE=0.460)**
Amount of inventory held by your warehouses to meet demand requirements	0.575
Amount of space reserved in warehouses in case of sudden changes in demand	0.774
Extent to which demand at a specific location can be reassigned to a different location	0.728
Number of worldwide storage/distribution facilities	0.618

Table 10. Comparison of factor loadings and reliability for risk measures

Risk scales and associated items	Impact*Probability λ_i	Wagner & Bode (2008) λ_i
Supply Risk*	**(CR=0.848; AVE=0.445)**	**(CR=0.828; AVE=0.497)**
Poor logistics performance of suppliers (delivery dependability, order fill capacity)	0.639	0.824
Sudden default of a supplier (e.g., due to bankruptcy)	0.659	0.711
Supplier quality problems	0.646	0.797
Poor logistics performance of logistics service providers	0.667	0.636
Capacity fluctuation or shortages on the supply markets	0.732	0.513
Demand Risk*		**(CR=0.833; AVE=0.713)**
Unanticipated or very volatile customer demand	0.585	0.877
Insufficient or distorted information from your customers' quantities about orders or demand	0.731	0.811
Internal Risk**	**(CR=0.897; AVE=0.685)**	**(CR=0.817; AVE=0.529)**
Downtime or loss of own production capacity due to local disruptions (e.g., fire, industrial accidents, etc.)	0.793	0.82
Perturbation or breakdown of internal IT infrastructure (e.g., caused by computer viruses, software bugs)	0.853	0.724
Loss of own production capacity due to technical reasons (e.g., machine deterioration, poor quality)	0.798	0.705
Perturbation or breakdown of external IT infrastructure	0.864	0.649

Note: *Supply and Demand risk are combined as a single construct, external risk, in this study. The collective composite reliability and average variance extracted are shown. The comparative values are Supply: CR=0.802; AVE=0.448 and Demand: CR=0.607; AVE=0.438
**Wagner and Bode (2008) originally titled this risk 'infrastructure' but was renamed for consistency in this paper.

3.3. Data analysis

3.3.1. Measurement Invariance

The next step of my analysis is to show that the meaning of constructs does not vary between countries. To accomplish this, I tested for measurement invariance across the three countries; refer to Table 11, 12 & 13. Since the objective of the analysis is to compare the means of the constructs between countries, full metric invariance is not required, nor likely considering the strictness of the invariance requirements (Horn, 1983). Metric and scalar invariance of at least two items per construct is required to make defensible quantitative group comparisons of means

(Byrne et al., 1989; Meredith, 1993). I conduct each step in the measurement invariance process while focusing on the two forms of invariance required to test differences in means of the constructs between countries.

Measurement invariance is a stepwise process which progressively adds stricter constraints to the measurement model. The first step is to estimate a CFA including a country level latent variable with all parameters freely estimated. Parameters are constrained to be equal across countries in the following order: factor loadings, intercepts, residuals, factor means, and variances (Gregorich, 2006). Invariance is supported when the chi-square test between models is insignificant (i.e. not rejecting the null hypothesis, H_o: measurement is not different between groups) or the stepwise CFI increments is less than .01 (Vandenberg and Lance, 2000).

The null hypothesis was rejected for every step in the invariance test procedure for the measure of flexibility. Thus, flexibility did not display measurement invariance and pooling the data without accounting for country differences would result in biased estimates. Conducting a post-hoc inspection of modification indices shows most factor loading are not invariant across groups. The required change in the hypothesized model would be too drastic to selectively relax constraints and pursue partial metric invariance. For the other two constructs, redundancy and risk, metric invariance was displayed, but only one of the stricter tests of invariance were supported. Metric invariance refers to an insignificant difference of factor loading between countries, suggesting that the meaning of the constructs is the same across countries. For the redundancy measures, modification indices indicated that two items' intercepts may be responsible for the lack of scalar (strong) invariance. The intercept constraints of the first items for demand and supply were relaxed based on the modification indices, resulting in a significant improvement in model fit in comparison to the original scalar invariance model ($\Delta\chi^2$ (4) 105.18,

$p<0.001$) and an insignificant fit in comparison to the metric invariance model ($\Delta\chi^2$ (12) 5.12, $p>0.1$). Thus, partial scalar invariance was supported for redundancy and the means of the latent constructs can be compared meaningfully across countries using the partial invariant model.

Turning to the risk measures, partial scalar invariance may also be achieved if a couple of the constraints on item intercepts are relaxed. Upon inspection, modification indices suggest that the last external risk item is primarily responsible for the poor fit. Also, the fifth external risk item for Japan appears significantly different than both Australia and USA. Therefore, the constraint that the fifth external risk intercept be constant for Australia and USA is retained, while the other two intercepts are relaxed. Comparing the fit statistics of the partial model to the metric invariance model provided support for partial scalar invariance ($\Delta\chi^2$ (15) 18.05, $p>0.1$) while showing a marked improvement over the original model ($\Delta\chi^2$ (3) 30.85, $p<0.001$). Both chi-square difference and CFI difference test provided the same evidence of null hypothesis rejection for every test conducted.

The only stricter form on invariance that was observed for risk and redundancy was full measurement invariance, despite each step leading up to it being significant. This indicates that the variances of the items are invariant, but the residuals and means are not. Thus, pooling the data is inappropriate for conducting statistical tests such as path analysis. Since this is beyond the scope of this paper, I do not pursue testing for partial invariance at stricter levels of measurement invariance. I note however, that this result has significant implications for researchers conducting international survey studies on supply chain risk management. Pooling data must be done with caution and may lead to erroneous conclusions if done without measurement invariance.

Table 11. Measurement invariance: Flexibility

Model	Hypothesis	Test	Description of Hypotheses	χ^2 (d.f.)	$\Delta\chi^2$ (d.f.)	*p*	CFI	ΔCFI
1	Base	-	All parameters free	462.40 (132)			0.755	
2	Metric invariance	2/1	Factor loadings are constrained to be equal across groups	511.65 (148)	49.25 (16)	0.000	0.731	0.024
3	Strong invariance	3/2	Factor loadings and intercepts are constrained to be equal across groups	564.92 (164)	53.27 (16)	0.000	0.703	0.028
4	Strict invariance	4/3	Loadings, intercepts and residuals are constrained to be equal across groups	603.87 (180)	38.95 (16)	0.001	0.686	0.017
5	Strict invariance plus factor means	5/4	Loadings, intercepts, residuals and factor means are constrained to be equal across groups	645.92 (186)	42.05 (6)	0.000	0.659	0.027
6	Strict invariance plus factor means & variances	6/5	Loadings, intercepts, residuals, factor means and variances are constrained to be equal across groups	668.15 (198)	22.23 (12)	0.035	0.652	0.007

Table 12. Measurement invariance: Redundancy

Model	Hypothesis	Test	Description of Hypotheses	*χ2* (d.f.)	Δ*χ2* (*d.f.*)	*p*	CFI	ΔCFI
1	Base	-	All parameters free	750.47 (132)			0.447	
2	Metric invariance	2/1	Factor loadings are constrained to be equal across groups	767.61 (148)	17.14 (16)	0.377	0.446	0.001
3	Strong invariance	3/2	Factor loadings and intercepts are constrained to be equal across groups	877.91 (164)	110.30 (16)	0.000	0.361	0.085
4	Strict invariance	4/3	Loadings, intercepts and residuals are constrained to be equal across groups	904.72 (180)	26.81 (16)	0.044	0.352	0.009
5	Strict invariance plus factor means	5/4	Loadings, intercepts, residuals and factor means are constrained to be equal across groups	919.55 (186)	14.83 (6)	0.022	0.344	0.008
6	Strict invariance plus factor means & variances	6/5	Loadings, intercepts, residuals, factor means and variances are constrained to be equal across groups	937.60 (198)	18.05 (12)	0.114	0.333	0.011

Table 13. Measurement invariance: Risk

Model	**Hypothesis**	**Test**	**Description of Hypotheses**	**χ^2 (d.f.)**	**$\Delta\chi^2$ (d.f.)**	***p***	**CFI**	**ΔCFI**
1	Configurational Invariance	-	All parameters free	739.13 (135)			0.593	
2	Metric invariance	2/1	Factor loadings are constrained to be equal across groups	753.03 (153)	13.9 (18)	0.736	0.588	0.005
3	Scalar invariance	3/2	Factor loadings and intercepts are constrained to be equal across groups	801.93 (171)	48.90 (18)	0.000	0.557	0.031
4	Strict invariance	4/3	Loadings, intercepts and residuals are constrained to be equal across groups	847.41 (189)	45.48 (18)	0.000	0.543	0.014
5	Strict invariance plus factor means	5/4	Loadings, intercepts, residuals and factor means are constrained to be equal across groups	864.52 (193)	17.11 (4)	0.002	0.532	0.011
6	Strict invariance plus factor means & variances	6/5	Loadings, intercepts, residuals, factor means and variances are constrained to be equal across groups	866.33 (199)	1.81 (6)	0.936	0.529	0.003

Full metric invariance along with partial scalar invariance was observed for the measures of redundancy and risk, allowing us to proceed to the next step in testing the differences in constructs between countries. Note, while flexibility did not display measurement invariance, I still include it in the further analyses for completeness with the understanding that differences in mean values are likely a result of the latent variables having different meanings across countries and not to culture. I test the differences in latent means by including a path from an observed country construct to the latent variables (Dimitrov, 2006). Since country is a categorical variable, I estimate the means using a generalized structural equation model (GSEM) in Stata 14. With the USA as the reference group, the path from Australia to both internal and external risk is insignificant while for Japan, external risk and internal risk are both positive and significant ($\overline{Riskex}_{jap}$ = 1.88, p <0.10 & $\overline{Riskin}_{jap}$ = 3.48, p <0.01); see Table 14. To compare Australia and Japan, Australia was held as the reference group. For internal risk, Japan and Australia displayed no significant difference while external risk was significantly higher in Japan ($\overline{Riskex}_{jap}$ = 2.87, p <0.05). Analysis of the difference in redundancy reveals a similar pattern but in the opposite direction. Redundancy was significantly lower in Japan than the USA ($\overline{Redsup}_{jap}$ = -0.73, p <0.001; $\overline{Redpro}_{jap}$ = -0.78, p <0.001; $\overline{Reddem}_{jap}$ = -0.73, p<0.001). Process redundancy was significant and negative when comparing Australia to the USA ($\overline{Redpro}_{aus}$ = -0.36, p<0.05). With Australia as the reference group, all three dimensions of redundancy for Japan were significant and negative ($\overline{Redsup}_{jap}$ = -0.48, p <0.05; $\overline{Redpro}_{jap}$ = -0.42, p <0.10; $\overline{Reddem}_{jap}$ = -0.49, p <0.05). For flexibility, Japan and Australia are not significantly different, while the USA has positive and significantly greater supply and process flexibility than Australia ($\overline{Redsup}_{USA}$ = 0.53, p <0.01; $\overline{Redpro}_{USA}$ = 0.58, p <0.05). With the USA as the reference group, Japan has a significant and negative level of flexibility for each dimension ($\overline{Redsup}_{jap}$ = -0.82, p <0.001; $\overline{Redpro}_{jap}$ = -1.00, p <0.001; $\overline{Reddem}_{jap}$ = -0.76, p <0.01).

Table 14. GSEM Construct Between Country Comparison

	Japan-USA		**Japan-Aus.**		**Aus.-USA**	
	λ_i	se	λ_i	se	λ_i	se
External Risk	1.882^{+}	(1.117)	2.024	(1.371)	-0.141	(1.213)
Internal Risk	3.480^{**}	(1.101)	2.866^{*}	(1.340)	0.614	(1.173)
Supply Flex	-0.817^{**}	(0.181)	-0.285	(0.216)	-0.532^{**}	(0.193)
Process Flex	-0.995^{**}	(0.231)	-0.414	(0.270)	-0.581^{*}	(0.235)
Demand Flex	-0.764^{**}	(0.276)	-0.297	(0.339)	-0.468	(0.300)
Supply Red	-0.731^{**}	(0.191)	-0.476^{*}	(0.231)	-0.255	(0.204)
Process Red	-0.778^{**}	(0.186)	-0.416^{+}	(0.225)	-0.362^{+}	(0.185)
Demand Red	-0.735^{**}	(0.167)	-0.493^{*}	(0.192)	-0.241	(0.163)

Note: ^{+}p<0.1, *p<0.05, **p<0.01

Figure 4. Risk Mitigation Comparison

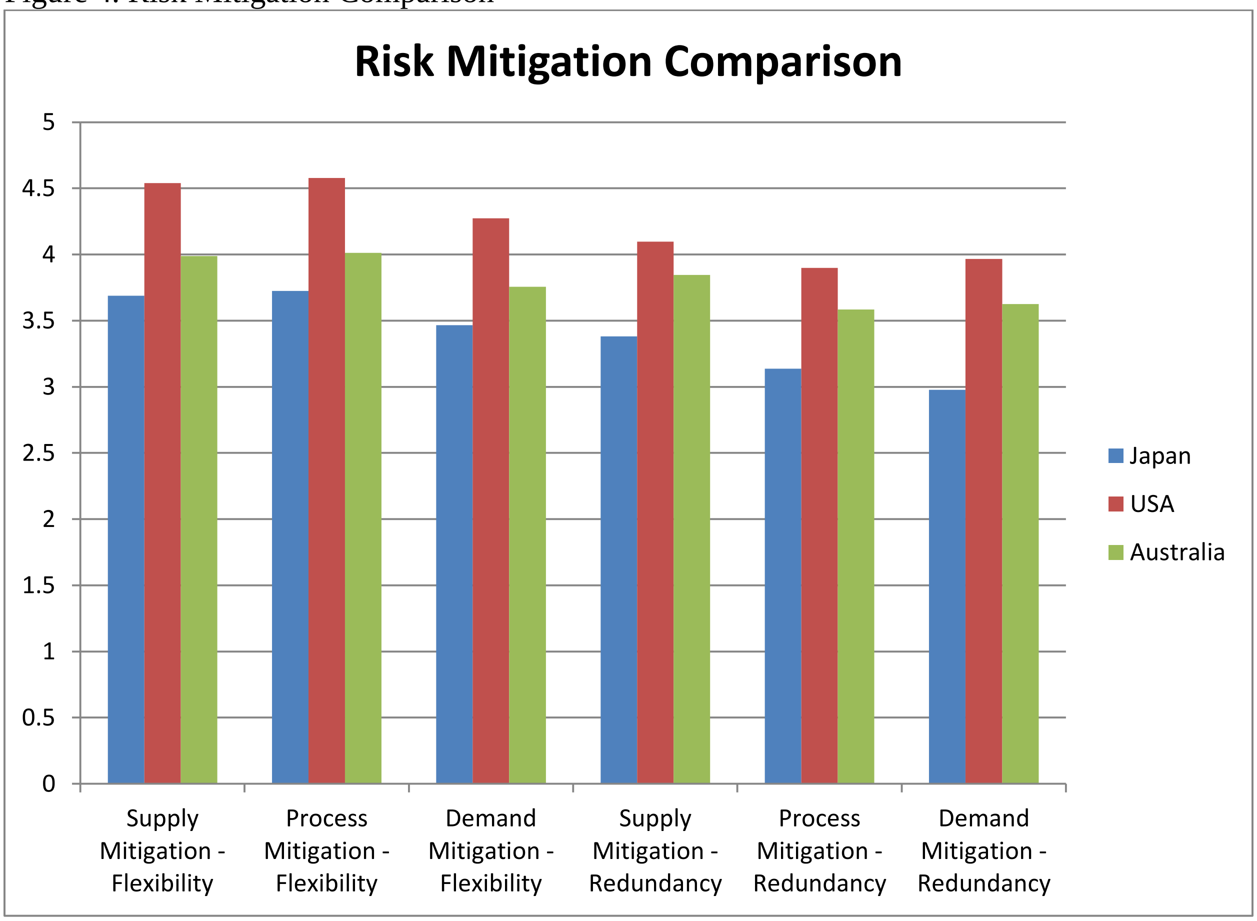


Figure 5. Perceived Risk Comparison

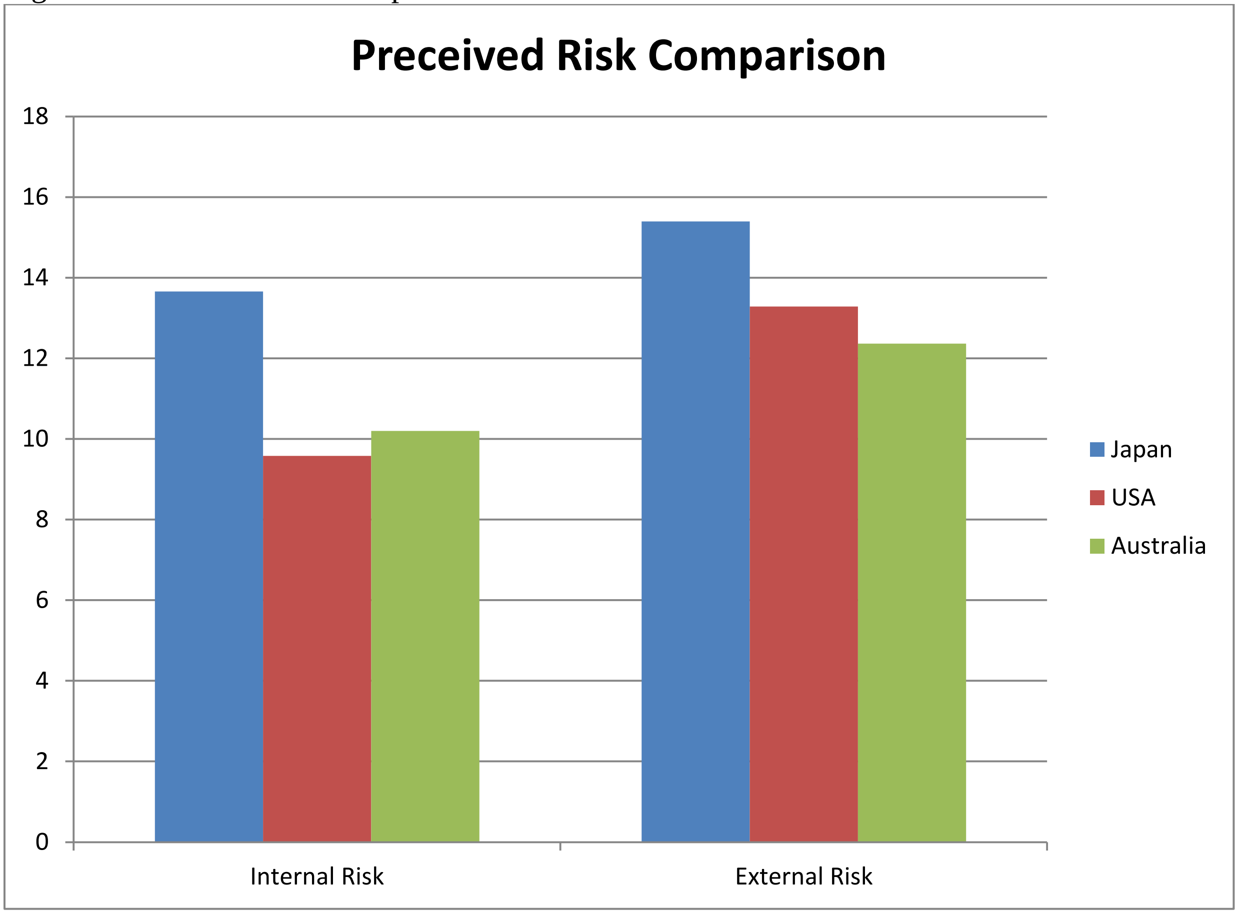


Table 15. MANOVA results

	Japan			USA			Australia			MANOVA					
Variable	**N**	**Mean**	**σ**	**N**	**Mean**	**σ**	**N**	**Mean**	**σ**	**Japan-US**		**Japan-Aus.**		**US-Aus.**	
External Risk	56	15.392	6.525	109	13.288	7.985	44	12.368	7.163	2.77	0.010	3.91	0.001	1.31	0.248
Internal Risk	56	13.661	6.819	109	9.580	7.389	44	10.199	8.311	3.40	0.011	3.96	0.005	1.21	0.307
Absorbed Slack	57	3.626	1.386	110	4.464	1.108	44	3.919	1.433	6.26	0.000	2.38	0.010	1.44	0.155
Unabsorbed Slack	56	3.165	1.199	110	3.988	1.039	44	3.686	1.260	3.94	0.000	1.28	0.247	2.28	0.011

3.3.2. Robustness

CFA accounts for the multidimensionality of reflective latent constructs, but the measures may also be thought of as formative since they consist of practices firms use to create redundancy and flexibility in their supply chains. Since the distinction between reflective and formative measures is not always perfectly clear, I use a MANOVA to show the differences between the constructs, further supporting my analyses. Wilks' criteria, F tests, and their associated p value for each of the country differences are displayed in Table 15. The MANOVAs were conducted for each of the three pairs of countries in the sample. Perceived internal and external risks are significantly different between both US and Japan and Australia and Japan. There is not a significant difference in perceived risk between US and Australia, providing further support that the difference is due to cultural dimensions. Despite the higher perceived risk in Japan, the level of risk mitigation is significantly lower in Japan than USA for both flexibility and redundancy. Meanwhile, there is no significant difference in flexibility between the US and Australia, while there is a significant difference between Australia and Japan. For redundancy, there is a significant difference between the USA and Australia, but not one between Japan and Australia. This suggests that the difference in flexibility may be cultural while the difference in redundancy could be due to regional or other constraints in the supply chain.

4. Discussion

This study develops a measure of risk mitigation and investigates differences in both the perception of supply chain risk and the usage of risk mitigation strategies in different countries. I advance the theoretical distinction between two types of risk mitigation strategies based on how they function and refine their measurement. This is an important contribution to the literature because without consistent language and proper measurement, research cannot advance a field

(Meredith, 1993). By leveraging theories on slack, flexibility and redundancy are argued to have unique characteristics that mitigation risk in fundamentally different ways. The challenges in measuring risk were also explored and I show that care must be taken when measuring risk over broad regions since differences in culture may affect how people respond to questions regarding risk.

Flexibility and redundancy are both effective methods for reducing risk and they should not be viewed as being implemented independent of the other, but rather as different options that may be used to combat risk in a unique ways. The two risk mitigation strategies may be used in combination or independently. Reiterating claims made in the literature on slack, I emphasize that flexibility and redundancy need to be applied based on the threats a firm is exposed to coordinating them across the supply chain is vital for building resilience. I contribute to the literature by further advancing the importance of flexibility and redundancy as risk mitigation strategies while developing a measure for redundancy. I argue that these forms of slack are unique in classifying strategies firms implement to buffer against uncertainty. Additionally, I encourage future studies to clearly articulate which stage of the risk management process they are focusing on and to account for the application of slack across the supply chain.

In contrast to the neoclassical economic view, slack is not always a waste that needs to be optimized out of a system, but a necessary parameter in maximizing long term financial sustainability. The types of slack applied in different countries were shown to vary significantly. Japan, despite their high perceived risk, implements lower levels of both flexibility and redundancy than the two western culture countries. This is important for supply chain risk managers to realize as it may impact the types and levels of strategies they apply internally.

Understanding the differences between cultures may improve communication between supply partners, which in turn may improve the resilience of a supply chain.

Flexibility did not exhibit measurement invariance. While this result did not allow for the comparisons between countries to be associated to cultural differences, it suggests that how flexibility is understood varies between countries. This may be a result of the complexity of unavailable slack. Flexibility is a more complex form of slack than redundancy since redundancies are easily quantifiable and more universal in operations management. The degree and location of unavailable slack can vary substantially within the operations of a firm, potentially influencing how each respondent across country or firm boundaries understands the construct. Extra precaution must be taken in administering surveys on flexibility for mitigating risk.

Supply chain risks extend beyond firm boundaries, requiring careful coordination between suppliers, distributors and retailers to ensure adequate risk mitigation strategies are in place. However, suppliers may not share the same perspective on risk which may result is misappropriated resources to mitigate them. In this study I show that the perception of risk and the degree to which risks are mitigated varies significantly across cultural borders. Communication is necessary for a resilient supply chain (Chopra and Sodhi, 2004; Stevenson and Spring, 2007). Without an understanding that suppliers from regions with well-defined cultural differences have systematic different understanding of what their exposure to risk is, coordinating risk management may be ineffective. I hope that this study informs managers of how cultural differences manifest themselves in the context of risk management so that communication and resource allocation is improved.

4.1. Limitations

Unfortunately, this study suffers from several drawbacks that limit its empirical potential. While redundancy and risk both display partial scalar invariance, they are not invariant at the stricter levels required to pool the data and conduct path analysis. Requiring respondents with the specific profiles necessary for this study made it difficult to meet the high observation requirements of SEM. As a result, I only received 109 usable surveys from the USA, 58 from Japan and 44 from Australia. Even with a simple model, using the appropriate methodology for reflective psychometric constructs, SEM, only permits estimating between 10 and 43 free parameters using the recommended 20:1 to 5:1 ratio for sample size to free parameters. In order to conduct path analysis with data from different countries that are not strictly invariant, GSEM is the recommended methodology to account for higher order country effects. The number of free parameters required to estimate higher order GSEM models increases by a multiple of the number of groups in comparison to traditional SEM, increasing the sample size requirements considerably. I attempted to reduce many of the drawbacks of the survey methodology and in the future would like to pursue alternative methods for measuring risk mitigation to further limit the challenges of survey research.

Managerially, understanding these difference is important since supply chain are international and working with supply chain partners with different perceptions of risk and risk mitigation practices can be problematic for several reasons. When creating supply contracts, difference is risk perceptions may lead to different valuations of a contract and inhibit negotiation. Alternatively, parties from different countries may be negotiated on different terms, leading to a false understanding that may lead to conflict. Risk may also be transmitted through a supply chain based on the practices adopted by supply chain partners. A firm may be impacted by the misalignment in risk mitigation practices between their supply partners. For example, a supply partner may focus on unavailable slack in the form of machine flexibility, meanwhile have high capacity utilization with the expectation that the downstream partners utilize available slack, such as keeping an adequate about of safety stock. Once an unforeseen spike in demand occurs, the risk may be amplified downstream.

Chapter 4 - Evaluating the Performance of Risk Mitigation Systems: A Frontier Approach

1. Introduction

Global supply chains are fraught with risk and managing these risks is an integral part of any organization. The risk management literature stresses the strategic importance of supply chains and that they be resilient to disruptions in the flow of materials and information (Narasimhan and Talluri, 2009; Sodhi and Tang, 2012). In the quest to build resiliency, most firms invest in risk mitigation strategies to limit the cost and likelihood of a disruption taking place. Yet, these investments may counter the fundamental premise of efficiency with which the supply chain operates. Thus, simply implementing a system of risk mitigation policies, procedures, and activities is not always effective. Tony Hayward, former CEO of British Petroleum (BP), focused on improving risk management within the organization when he was hired in 2007. Despite his strategic orientation toward managing risks, the catastrophic Deepwater Horizon oil spill in the Gulf of Mexico happened while he was in charge of the company. Not only did the loss of the oil rig disrupt BP's supply chain, it resulted in fines and restoration efforts that cost BP billions of dollars. The root cause of the incident was identified by an U.S. government committee as a failure in"…the ability of individuals involved to identify the risks they faced and to properly evaluate, communicate, and address them." (Kaplan and Mikes, 2012, p. 48). Evaluating risk and their mitigation strategies could have helped BP avoid the disaster or reduce its impact. Evaluation is a prerequisite for the other two steps highlighted in the investigation, communication and addressing risk, since information from the evaluation can be used as a benchmark for improvement and is easily communicated. It is also important to evaluate the returns on investments of risk mitigation strategies across the supply chain. Assessing the effectiveness of implementing these strategies also aligns with the supply chain's fundamental goal of improving efficiency. This issue forms the core research question of this study: from a central planner's perspective, how can firms most effectively evaluate the performance of their risk mitigation strategies?

Evaluating supply chain risk mitigation strategies presents multiple challenges. First, each firm faces a unique set of risks and has many choices in the strategies to adopt that may mitigate those risks. This presents a situation of equifinality; there are multiple paths to take to achieve a specific goal (Doty and Glick, 1994). Second, risk and the mitigation strategies adopted to address them are often linked. Supply chains are not monolithic entities and as the flow of goods are dependent on each linkage in the chain, so too are risk mitigation strategies. For instance, O'Riely (2014) notes that implementing dual sourcing as a risk mitigation strategy may not be effective without considering reliability of downstream activities. In another example, the textile industry is known for its lack of flexible supply capacity so contracts are fixed far in advance, increasing the risk of stockouts and excess inventory (Eppen and Iyer, 1997). In order to mitigate this risk, backup agreements can be used to increase the flexibility of obtaining goods from a supplier, but this may have implications for other risks a firm is exposed to and the strategies used to mitigate them. Specifically, the type, quantity and location of inventory may be impacted as well as the modes of transportation of the goods to the market. In contrast, semiconductors have a long production run times and short technology cycles. This environment requires different approaches to mitigating risk than the textile industry, such as flexibility in plant design, number of backup suppliers, and new product development processes. Thus, a combination of the diverse risk mitigation methods throughout the echelons of the supply chain requires firms to coordinate the different approaches of mitigating risks. Lastly, resources are limited in any firm, so the cost of risk mitigation is a critical component of evaluation. Thus, it is the job of a supply chain manager to critically assess the resources channeled to risk mitigation effort and the consequent outcomes obtained from these efforts. In accounting for these challenges, this study proposes a method for evaluating risk mitigation strategies that addresses each of the aforementioned challenges.

Firms must balance potentially conflicting objectives of cost efficiency of strategies pursued while minimizing supply chain risks (Lee et al., 2004). Whether it is holding extra capacity, stocking extra inventory, developing options contracts, or establishing secondary supply sources, implementing risk mitigation strategies come at a cost beyond what is necessary to deliver value to customers. Many performance measurement techniques, such as the balanced scorecard (Kaplan and Norton, 1996), fail to account for cost while only focusing on performance levels. Evaluating the performance of risk mitigation strategies must account for the cost of them to facilitate the appropriate allocation of resources among the strategies that provide the greatest reduction in risk. Further complicating the decision making process, these costs are borne regardless of a disruption occurring and the likelihood of a disruption is uncertain. O'Reilly (2014) highlights the difficulty in balancing meeting demand and overinvesting. Part of the reason is that managers view the cost of mitigation as an insurance premium and the return on investment is difficult to quantify (Sheffi, 2001). Specifically, managers can invest significant resources to minimize the risk, but that may not benefit the firm overall due to high costs. In this regard, to create a cost-efficient supply chain that is resilient to disruptions, risk mitigation strategies themselves must be implemented efficiently (Tang, 2006a). The varying cost and effectiveness of different methods of mitigating risk demand efficient utilization of resources applied to the appropriate sources of risk is a key objective of performance evaluation.

Literature on supply chain risk management is growing significantly and several facets have been studied. However, measurement and evaluation literature in risk management is at a nascent stage. This study aims to fill those gaps and makes multiple contributions to the literature. First, most of the current risk management literature considers the supply chain as either a monolithic entity or as individual and independent parts. I acknowledge the importance of each element in the supply chain and develop a comprehensive framework of risk that considers each of these entities and the interdependences between them using a Network Data Envelopment Analysis (NDEA). It is likely that firms may gain differentially from investing in each aspect of their supply chain and the NDEA analysis allows us to investigate how these elements help mitigate risk. Second, Ambulkar et al. (2015) focus on resilience as a key component of supply chain risk. However, building resilience is expensive and none of the current studies in the literature have focused on measuring the costs of building resilience. I fill this gap by measuring the costs of risk mitigation strategies in addition to the level of implementation. I note that this gap in the literature is particularly relevant with respect to the orientation for efficiency within supply chain management. To illustrate, I demonstrate the importance of including cost when evaluating the performance of risk mitigation practices to better understand the cost benefit trade-offs in supply chain risks through the use of a NDEA approach. NDEA uniquely allows identification of these trade-offs. Specifically, cost benefit trade-offs may not just happen between individual strategies (such as flexibility and redundancy), but across different entities in the supply chain. For example, firms may more efficiently mitigate one component of supply chain risk as compared to others, while another may be more efficient in process risk mitigation, and still be at the frontier.

2. Literature Review

The literature most relevant to this study is that of supply disruptions and supply chain performance evaluation. Within these literature streams, I focus the review on research that quantifies risk mitigation practices for performance evaluation of supply chain risk. Mitigating risk can be accomplished using various practices and is a vital component of the supply chain risk management process (Kleindorfer and Saad, 2005). Kern et al. (2014, p.81) define risk mitigation as a process that "…incorporates all activities concerned with deciding how to deal with a certain risk and executing the chosen strategy." The practices that can be used to mitigate supply chain risk vary substantially, from collaboration to geographic dispersion; refer to (Ceryno et al., 2015) for a comprehensive list. Mitigation strategies are used to manage many types of risks, such as establishing improved supplier relationships to increase upstream visibility or adopting revenue management policies to shift demand, thereby reducing demand fluctuations. Thus, classification systems are often developed to distinguish the mitigation strategies according to the risks they mitigate or the mechanism by which they function. While several such classifications have been proposed, redundancy and flexibility are two of the most common (Braunscheidel and Suresh, 2009; Chopra and Sodhi, 2004; Kern et al., 2012). Accordingly, I focus on these two for this study. Redundant and flexible risk mitigation strategies differ based on the mechanisms of risk mitigation. I define redundancy as, the provision of duplicate resources to ensure business continuity in the case of a risk event. Inventory, multiple suppliers of the same components, and multiple production facilities that produce the same products are redundant mitigation strategies. Flexibility is defined as, the ability of a firm to easily change or adapt resources to ensure business continuity in the case of a risk event. Examples of flexibility are options contracts with suppliers or equipment that can be used to produce many different products. Flexibility has been argued to be the better of the two in mitigating risk (Talluri et al., 2013), but a comprehensive risk mitigation system likely requires both. Further, a balance must be made with these strategies depending on the specific environment a firm is in.

With many different sources of risk and methods to mitigate them, a one-size fits all approach is inappropriate. Thus, a 'tailored' strategy is required (Chopra and Sodhi, 2004), suggesting that there are multiple ways to achieve a cost-efficient low risk supply chain. This situation of equifinality has been further categorized into 4 types, based on the degree of conflict in functional demands and the latitude of structural options (Gresov and Drazin, 1997). Based on the classification of Gresov and Drazin (1997), a risk mitigation system would be classified as 'Configurational Equifinality' since there are many strategies that can be adopted and many types of risk to mitigate. Specifically, there is not an ideal set of practices that will result in the highest performance, which needs to be accounted for during performance evaluation and measurement. Under this form of equifinality, the performance of an organization, "…results from identifying a subset of functional demands that minimize functional conflict, and matching these demands with a set of appropriate structural features that are internally consistent" (Gresov and Drazin 1997, p.416). This highlights two of the dilemmas in performance measurement of risk mitigation: deciding which strategy to pursue and benchmarking. Specifically, effective performance management (PM) provides a benchmark for strategy (Koufteros et al., 2014) and is a critical link between strategy implementation and its financial effectiveness (Melnyk et al., 2004). Yet, the literature on supply chain risks is scant on methods to measure the performance of risk mitigation strategies.

2.1. Performance Measurement

Many scholars have developed frameworks and argued for the value of PM systems (Bititci et al., 1997; Bititci and Turner, 2000; Neely et al., 2005; Gunasekaran et al., 2001; Estampe et al., 2013). The importance of an effective PM system to assess risk mitigation is highlighted by a firm's resource limitations and the strategic importance of a firm's supply chain. In the context of a supply chain, measuring the performance of the supply chain as a whole has been shown to be a key element of firm competitiveness (Gunasekaran et al., 2001). In order for a supply chain to perform smoothly, it must be resilient to disruptions, suggesting that risk management should be considered as an integral part of PM for a supply chain. While investing resources in risk mitigation is important, how they are deployed is argued to be as important as which resources are possessed by a firm (Hansen, 2004). Further, these resources need to be 'orchestrated' to maximize their effectiveness (Sirmon et al., 2011). Koufteros et al. (2014) show that the orchestration of resources is facilitated by PM. PM may improve supply chain performance by improving decision making and facilitating effective strategy implementation (cf., Henri 2006). Extending these arguments to risk mitigation is especially relevant since the resources invested in risk mitigation may not be directly applied toward delivering value to customers, but rather act as an insurance (Sheffi, 2001). Accordingly, these resources need to be allocated as efficiently as possible.

As a rule, managers want to avoid any negative impact from the risks they face and adopting flexibility and redundancy risk mitigation strategies is considered good practice (Sheffi and Rice Jr, 2005). However, the extent and type of risk mitigation strategies that firms need to implement to achieve specific outcomes is not as clear. Supply chain risk is unique in that risks are inter-connected because supply chains are interdependent across its stages. This presents a situation where investments in individual stages may have a differential influence on the efficiency of risk mitigation. Ritchie and Bradley (2007) echo this argument as it is a key aspect in their framework relating risk mitigation and performance measurement. Similarly, Lambert and

Pohlen (2001) argue that PM systems should reflect the organizational structures. Yet, current studies relating to risk mitigation in supply chains do not take this inter-connected nature of various supply chain stages into account. Accordingly, in this study, I categorize the inter-connected risks and mitigation strategies as supply, process and demand since they represent the flow of materials through a supply chain which accounts for the requirement of PM in operations along the stages of the supply chain (Fortuin, 1988). Each stage of the supply chain has specific risk mitigation practices associated with it and these practices are reviewed in the following sections.

2.1.1. Supply risk mitigation

Despite the fact that supply chain risk involves more than just the supply side of a firm's operations, measuring supply risk mitigation strategies have been the focus of more empirical research than either process or demand risk. Since this study is concerned with performance measurement, I acknowledge omitting many important studies from the literature review, but I focus on empirical articles that cover the measurement of risk mitigation strategies. The measures used in the literature are primarily survey based and have not been very consistent. For instance, Avittathur and Swamidass (2007) surveyed supplier flexibility and showed it had an impact on growth, profitability, and inventory. However, this study was focused on positive outcomes and did not directly test the relationship of plant flexibility to supply chain risk. Wagner and Bode (2008) developed a broad six item measure of risk management that includes supply risk mitigation strategies, including business continuity plans, supplier collaboration, supplier monitoring, and insurance. Blome et al. (2012) show that supply chain agility fully mediates the relationship between supply competence and operational performance. The authors use a latent agility construct that captures the extent to which a firm can ‘adapt’, ‘react’, or ‘adjust’ to several supply and production activities.

Rather than mitigation, Groetsch et al. (2012) measure a similar construct of supply chain risk management reactiveness using a three item construct developed using context analysis of a set of interviews. Hoffman et al. (2013) provide the most direct measurement of risk mitigation by identifying 22 risk mitigation activities through a discussion workshop. The authors then refined their measure to 6 items that were used as a formative construct in an empirical model. Kern et al. (2012) also measure a latent construct of supply risk mitigation, but do so as a reflective, three item construct. Ellis et al. (2010) measure risk mitigation in their study on supply disruption risk as a single survey item of ‘search for an alternative supplier’. In their study on supply chain vulnerability, Wagner and Neshat (2012) developed a measure of supply chain risk planning and use three psychometric items that contain risk mitigation strategies to quantify it. While not intended to be exhaustive, these studies highlight the inconsistency of measuring risk mitigation and the importance of assessing their performance since each study relates risk mitigation to some form of performance.

2.1.2. Process risk mitigation

Mitigating disruptions due to demand or supply uncertainty are challenging because they involve actors external to the firm while risks in production processes are internal and should be more easily controlled. However, process risk still presents a difficult challenge for operations managers and is also a key element of supply chain risk. Both redundancy and flexibility are frequently studied as risk mitigation strategy in this context. For instance, smaller batch sizes (Betts and Johnston, 2005) and postponement (Tang and Tomlin, 2008) are examples of manufacturing activities that have been defined as flexible risk mitigation strategies.

Redundancies are very commonly applied in manufacturing to reduce risk and examples include overcapacity in production (Thun et al., 2011) and inventory (Hendricks et al., 2009). From a performance evaluation perspective, research on flexibility and redundancy have provided several measures of each type of risk mitigation strategy, but the tradeoff between cost-risk and other strategies still needs investigation (Vokurka and O'Leary-Kelly, 2000).

Several empirical measures of process flexibility have been developed using surveys, but not in the context of supply chain risk. In addition to supply flexibility, Avittathur and Swamidass (2007) used a survey to assess the impact of plant flexibility on growth, profitability, and inventory by quantifying plant flexibility as a factor score of four items. Other scholars have dissected plant flexibility into 5 dimensions: machine, material, product, labor and new product development flexibility (Koste et al., 2004; Patel and Jayaram, 2014; Patel et al., 2012). While there exists many measures of process flexibility and it is well established to improve competitiveness, few studies have investigated the impact of process flexibility on supply chain risk, despite the many qualitative and analytical studies supporting the relationship. In one example of secondary data analysis, Weiss and Maher (2009) showed in the airline industry that operational hedging mitigated the financial impact of the terrorist attacks on September 11, 2001. They provided four measures of operational hedging including fleet standardization, utilization, ownership and globalization, limiting the generalizability of the study to other industries. This study builds on this literature stream by applying flexibility to a performance evaluation framework for mitigating risks.

Arguably the most critical redundancy strategy used internally within a firm to buffer uncertainty is inventory. Inventory is a common buffer against supply and demand fluctuation since it is controlled internally and can be deployed immediately. Consequently, inventory is an important input to mitigating risk. Raw inventory and inventory turnover are widely adopted measures in practice and empirical research. For instance, Hendricks et al. (2009) show that days of inventory has no impact on negative stock market returns during a disruption. Additionally, inventory efficiency is positively associated with stock market returns and not significantly related to stock market risk (Mishra et al., 2013). Accordingly, inventory is an element of redundancy I examine as a process risk mitigation strategy. Further, I also account for the cost of inventory in examining its efficiency. Overall, I focus on both flexibility and redundancy as risk mitigating mechanisms internal to a firm in evaluating its overall supply chain risk mitigation system.

2.1.3. Demand risk mitigation

In a review of demand risk mitigation techniques, Ho et al. (2015) found four clusters of research: optimal-order placement, forecasting, contracts, and other. Although, most of that research is analytical so does not involve measurement in the performance evaluation process. Regardless, many of the studies in this domain highlight the key elements of mitigating demand risk. Demand risk is “risk associated with the outbound logistic flows and product demand” (Ceyrno et al. 2015, p.1150). Factors that contribute to product demand risk include inaccurate demand forecast, demand variability, and information distortion (Ho et al., 2015). Appropriate forecasting and flexibility in contracts are common methods of combating demand risk. For example, risk-sharing contracts have been shown to reduce risk for both the manufacturer and retailer (Chen, et al., 2006; Xiao and Yang, 2009). Quantity flexible contracts, for example, help absorb demand fluctuations and reduce demand uncertainty (Kim, 2013). The forecasting models that have been proposed as methods to mitigate product demand risk include the macro-prediction market model (Guo et al., 2006) and the generalized autoregressive conditional heteroskedastic model (Datta et al., 2007).

Logistic flow risks require different mitigation strategies than product demand uncertainty to mitigate risk and research on product demand exceeds that of logistic flow significantly. Vehicle routing is the most common method for mitigating logistics risk (Giaglis et al., 2004). Due to the increased use of information technologies and advances in computing power, vehicle routing is possible to be adjusted in real time, offering flexibility that could reduce risk. In the event of a disruption, Beroggi and Wallace (1995) show that real-time tracking information can be used by applied with decision support systems to minimize cost and risk associated with an unexpected event. Zhang et al. (2009) developed a greedy upper bounding and Lagrangian relaxation algorithm to show an optimal method for rerouting in the case of interruptions in the flow in a manufacturing facility. Other methods for mitigating logistic flow risk are maintaining excess distribution capacity and flexible distribution channels (Huchzemeier and Cohen 1996; Cohen and Huchzemeier 1999; Novaes 2000). Huchzemeier and Cohen (1996) and Cohen and Huchzemeier (1999) develop stochastic models that show how supply chain network design can reduce logistic flow risk. Novaes (2000) present a case to display the importance of logistic flow mitigation strategies.

While the studies presented above show that demand risk mitigation is effective at reducing demand uncertainty, the empirical measurement and testing of these present a gap in the literature. For instance, the two forecasting models developed by Datta et al. (2007) and Guo et al. (2006) do not attempt to measure the degree of forecasting used to mitigate demand risk, much less the effectiveness of these forecasting tools in practice nor the cost of implementing them. The other studies cited in this section follow a similar pattern. In summary, the studies on demand risk mitigation have not measured the strategies resulting in a lack of reliable methods to evaluate the performance of a risk mitigation system holistically.

Overall, the collective review of demand, process and supply risk reveals the following. First, supply side risk is the focus of most empirical research on supply chain risk and has been primarily been conducted by surveys. This may be a result of supply chain research fundamentally concerned with upstream suppliers and the difficulty is obtaining data on supply chain practices across firms. Second, several multi-item measures have been developed to measure supply risk mitigation strategies. However, these measures either measure flexibility or flexibility and redundancy practices are grouped together in a single latent construct of risk mitigation. From a theoretical and practitioner standpoint, more insight can be gained if the two strategies are studied in relation to one another than separately or grouped as a single construct. Furthermore, none of the current empirical studies measure the investment in risk mitigation strategies, a critical component of the total costs that firms invest to manage supply chain risk. This presents a conflict between the measurement and the supply chain objective of efficient deployment of resources. Accordingly, this study measures both mitigation of risks and accounts for the corresponding costs. I also measure mitigation strategies at each stage of the supply chain to achieve a more comprehensive evaluation of risk mitigation.

3. Methods

To build and test the performance evaluation methodology of a firm's risk mitigation system, I used the data collected in Chapter 3. I only used the sample from the United States of America to avoid issues due to cultural differences. See the previous chapter's method section for details. A third party was contracted to administer the internet based survey. Quality was ensured in collaboration with the third party by removing a) quick responses (less than 6 minutes), b) random or illogical responses, c) overuse of non-responses, and d) failed responses to the two attention filter items. Of the 803 responses, 285 did not meet the requirements for the survey and another 289 did not complete the survey. Collectively, I received a total of 229 complete responses which were then subject to the quality control procedure previously described, resulting in 109 usable responses. Non-response bias was tested by comparing the average size and revenue of the firms in the final sample to those of the non-respondents. As mentioned in the previous chapter, t-tests for both size and revenue were insignificant (size: p=0.53; revenue: p=0.84). Many different industries are represented, with a median firm age of 66 years. The majority of the sample was very experienced, with 10 years of cumulative experience, 35% of them being at their current position for that same length of time.

3.1. Measures

Flexibility was measured using a scale developed by Swafford et al. (2006) that included three dimensions of flexibility: procurement, manufacturing, and logistics. I renamed these dimensions in the study as supply, process, and demand respectively. This measure was chosen over other similar measures of flexibility because the items consisted of practices rather than outcomes of flexibility and it captures both the level (range) of flexibility and cost (adaptability) of the mitigation strategies. Redundancy was measured by creating a scale that mirrored the one used for flexibility, but replaced each item with practices classified in the literature as redundancy. For example, a measure of process redundancy 'Amount of capacity reserved in case of sudden changes in demand' reflects the process flexibility measure 'Number of product changeovers per manufacturing facility made each month' by capturing the redundant mechanism used in production to mitigate risk; refer to Table 17 for a full list of measures. Corresponding measures of cost, measured both in terms of money and time, were collected for each measure using the adaptability instrument developed by Swafford et al. (2006). In addition, a measure of financial performance was obtained independent of the survey instrument by the survey agency for each respondent and appended to the survey. This was done to limit common method bias, and is quantified as firm revenue. Size was also captured as a control variable, quantified as the number of employees that work for the firm.

To compare the proposed NDEA methodology to traditional approaches, I also operationalize flexibility and redundancy using confirmatory factor analysis (CFA). The validity and reliability of the measures was verified by creating two latent constructs of flexibility and redundancy, covarying them, and estimating the factor loadings of each of their respective items using maximum likelihood. The composite reliability of flexibility and redundancy were above accepted levels (Flexibility = 0.724; Redundancy=0.806). Discriminant validity was tested using two methods, the average variance extracted to squared error comparison and the Heterotrait-Monotrait cutoff (HTMT) as recommended by Voorhes et al. (2015). The Heterotrait-Monotrait ratio was less than the 0.85 cutoff ($HTMT_{.85}$ =0.387) and the average variance extracted for each measure was greater than the squared correlation between them (SE= 0.089; Flexibility AVE = 0.289 & Redundancy AVE = 0.222). The fit indices of the CFA were not ideal, but acceptable considering the loadings are only being used to create a factor variable as a comparison against the DEA based measure (χ^2 = 420.515, $p<0.01$; RMSEA=0.083, 90% CI [0.096, 0.070]; CFI = .805; SRMR= 0.110). Other descriptive statistics are shown in Table 17, 18 and 19.

Table 16. Demographic information

Firm characteristics	N	Median	Min	Max
Age (Years)	98	66	1	179
Risk management program (years)	101	2	0	50
Size (employees)	110	5,000 to 9,999	6 to 9	>25,000
Sales ($)	110	500 mill to 1 bill	50,000	>10 bill
Respondent characteristics	**N**	**Median**	**Min**	**Max**
Experience in firm	109	6 to 10 years	< 1 year	>10 years
Total experience	101	>10 years	1 to 3 years	>10 years
	Sent:	*Taken:*	*Qualified:*	
Response Rate	7280	738	109	

Industry sector	N	%	Respondent function		
Industrial Machinery	16	15.09	Supply chain management	18	17.31
Electronics	8	7.55	General management	19	18.27
Automotive	12	11.32	Logistics	15	14.42
Chemicals	8	7.55	Purchasing	41	39.42
Metal Working	5	4.72	Others	11	10.58
Pharmaceuticals	3	2.83	**Respondent job title**		
Consumer goods	11	10.38	CEO/vice president	10	9.17
Construction	2	1.89	Director/department head	36	33.03
General	16	15.09	Manager	60	55.05
Food, Beverages	5	4.72	Others	3	2.75
Aerospace, defense	8	7.55			
Telecommunication	2	1.89			
Banking / Financial Services	5	4.72			
Energy & Utilities / Oil & Gas	4	3.77			
Healthcare / Medical	1	0.94			

Table 17. Summary of Measures

	Risk Mitigation	Echelon	Items	Mean	St.Dev.
Level	Flexibility	Supply	4	4.665	0.863
		Process	4	4.805	0.992
		Demand	4	4.759	1.030
	Redundancy	Supply	4	4.342	0.894
		Process	4	4.317	1.032
		Demand	4	4.489	1.110
Cost	Flexibility	Supply	8	4.109	0.641
		Process	8	4.071	0.679
		Demand	8	3.898	0.851
	Redundancy	Supply	8	4.079	0.639
		Process	8	4.131	0.688
		Demand	8	4.002	0.715

Table 18. Comparison between aggregation methods

Risk Mitigation		Equal Weights	CFA	NDEA	DEA
Flexibility	Mean	4.743	11.887	0.542	0.711
	St.Dev.	0.709	1.930	0.213	0.176
	Min	2.917	6.210	0.281	0.403
	Max	6.583	16.547	1.000	1.000
Redundancy	Mean	4.382	5.981	0.516	0.641
	St.Dev.	0.869	1.393	0.248	0.169
	Min	1.750	2.727	0.247	0.370
	Max	7.000	10.467	1.000	1.000

Table 19. Correlation table (Kendall's tau)

	Flex. (CFA)	Red. (CFA)	Flex. (E.W.)	Red. (E.W.)	Flex. (NDEA)	Red. (NDEA)	Flex. (DEA)	Red. (DEA)	Revenue	Size
Flex. (CFA)	1.000									
Red. (CFA)	0.178 *	1.000								
Flex. (E.W.)	0.897 *	0.210 *	1.000							
Red. (E.W.)	0.236 *	0.552 *	0.265 *	1.000						
Flex. (NDEA)	0.344 *	-0.030	0.315 *	0.020	1.000					
Red. (NDEA)	-0.003	0.105	-0.013	0.205 *	0.201 *	1.000				
Flex. (DEA)	0.429 *	0.000	0.424 *	0.053	0.640 *	0.175 *	1.000			
Red. (DEA)	0.069	0.121	0.063	0.295 *	0.274 *	0.642 *	0.287 *	1.000		
Revenue	0.080	-0.159 *	0.083	-0.047	0.156 *	-0.034	0.157 *	0.041	1.000	
Size	0.068	-0.164 *	0.063	-0.138 *	0.130 *	-0.058	0.161 *	-0.020	0.435 *	1.000

Note: * p<0.05

3.2. Data Analysis

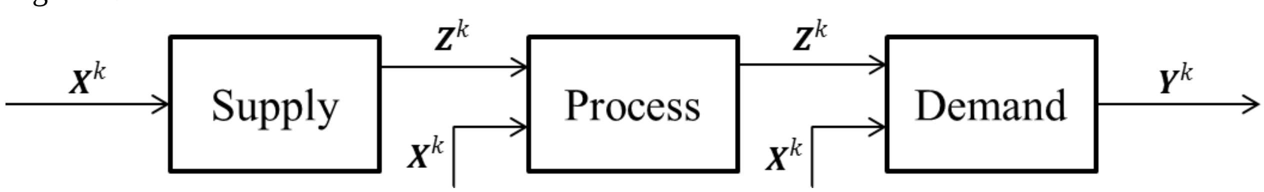
3.2.1. Modeling Efficiency of Risk Mitigation in a Network Context

Most research on risk mitigation strategies is focused purely on the level of mitigation strategy and not the cost of implementing them. For instance, Brandon-Jones et al. (2014) survey supply chain managers on the extent they use three risk mitigations: capacity, safety stock at the supplier and plant. While the level of mitigation strategies implemented is important, they are investments whose costs need to be considered in order to determine the financial impact they have. Incorporating the cost of risk mitigation is challenging in empirical research because it is often unavailable in typical secondary data sources. Accordingly, the input-output measures come from the survey I conducted. Further, this study is concerned with the performance measurement of risk mitigation, i.e., an efficient firm is one that maximizes risk mitigation at the least possible investment in relation to other firms. Thus, it was deemed appropriate to use a DEA methodology.

DEA is a mathematical programming method that calculates the efficiency of a decision making unit (DMU) at minimizing multiple inputs while maximizing multiple outputs. In this study, a DMU is a firm. Each firm receives a composite efficiency index ranging between zero and 1, with efficient firms receiving a value of 1. Firms with scores less than 1 can be interpreted as inefficient relative to the best firms in the sample. DEA assigns weights to all of the inputs and outputs based on the optimization formulation shown in equation 1, without assuming that the inputs and outputs are equally important or without subjectively assigning weights to them. Specifically, being an input-output approach, it allows us to examine the gains of risk mitigation vis-à-vis the cost of implementation.

In order to account for both the cost and interdependence of supply chain risk mitigation strategies, I adopted a NDEA model. NDEA is an extension to the DEA model frequently used in the management science literature that allows for a comprehensive optimization of a firm's productivity. A NDEA model relies on the same underlying optimization principles as DEA, but links the inputs and outputs of different stages together (each stage is referred to as a division). Thus, NDEA allows us to explicitly account for the interdependencies between inputs and outputs across the different stages of the supply chain. Past studies on risk mitigation do not explicitly consider these interdependencies across the various stages. This interdependency and NDEA model is illustrated in Figure 1. Traditional DEA analysis assumes independence of individual stages of the supply chain (and consequently risk mitigation strategies). This assumption is likely invalid since organizations are integrated and the coordination between divisions of the organization should have an impact on financial outcomes. Without accounting explicitly for the interdependence between stages of supply chain management may lead to inappropriate conclusions about the efficiency of individual risk mitigation practices, presenting a limitation in assessing risk mitigation efficiency.

Figure 6. Network DEA



I apply a input oriented variable returns to scale method, incorporating the cost of risk mitigation measured in both units of time and money as inputs and their respective degree of mitigation level as outputs. The optimization function minimizes the cost of risk mitigation relative to the level of risk mitigation. Thus, inefficient firms must minimize their inputs in order to reach the efficiency frontier. Outputs from one division, in this case supply, are added as inputs into the next stage, process, along with the original process inputs. This same dependence is captured in the optimization calculation linking process outputs to demand as inputs; refer to

Figure 6. There are n DMUs (j = 1,…, n) consisting of K divisions (k= 1,…, K). Let m_k and r_k be the number of inputs and outputs to division K. Linkages L from division k to h are denoted as (k,h). The mathematical expression of the objective function and corresponding constraints are shown below in equation 1.

$$\min_{\lambda^k, s^{k-}} \sum_{k=1}^{K} w^k \left[1 - \frac{1}{m_k}\left(\sum_{i=1}^{m_k} \frac{s_i^{k-}}{x_{io}^k}\right)\right] \tag{1}$$

$$\begin{aligned}
\text{s.t.} \quad & \boldsymbol{x}_o^k = \sum_{j=1}^{n} \boldsymbol{x}_j^k \lambda_j^k + s_j^{k-} && \forall k \\
& \boldsymbol{y}_o^k = \sum_{j=1}^{n} \boldsymbol{y}_j^k \lambda_j^k - s_j^{k+} && \forall k \\
& \sum_{j=1}^{n} e\lambda_j^k = 1 && \forall k \\
& \sum_{j=1}^{n} w_j^k = 1 && \forall k \\
& \sum_{j=1}^{n} \boldsymbol{z}_j^{(k,h)} \lambda^h = \sum_{j=1}^{n} \boldsymbol{z}_j^{(k,h)} \lambda^k && \forall k, h \\
& \lambda^k, s^{k-}, s^{k+}, w^k \geq 0, && \forall k
\end{aligned}$$

where s^{k-} and $s^{k+}$are the input and output slack variables respectively; the input, output and link vectors are represented as: $\boldsymbol{x}_j^k \in R_+^{m_k}, \boldsymbol{y}_j^k =\in R_+^{r_k}, \boldsymbol{z}_j^{(k,h)} \in R_+^{t_{(k,h)}}$; w^k is the relative weight of Division k, i.e. supply, process, and demand, and is adapted from the weighted stochastic block model (Cooper et al., 2007).

I also include a measure of flexibility and redundancy mitigation efficiency using a variable returns to scale slack based DEA model for comparison (Banker et al., 1984). The variable returns to scale model is identical to the original model developed by Charnes et al. (1978), but adds a convexity constraint to account for the asymptotic efficiency changes in output relative to input. The dual form of the linear program of the Banker, Charnes, and Cooper (BCC) model is presented below:

$$\begin{aligned}
& \min \theta_h - \varepsilon\left[\sum_i S_{ih}^{+} + S_{rh}^{-}\right] \\
& s.t. \quad \sum_j x_{ij}\lambda_j + S_{ih}^{+} = \theta_h x_{ih} \ \forall i \\
& \qquad\ \ \sum_j y_{rj}\lambda_j - S_{rh}^{-} \geq y_{rh} \ \forall r
\end{aligned}$$

$\sum_j \lambda_j = 1$

$\lambda_j, S_{rh}^{-}, S_{ih}^{+} \geq 0$

where S_{ih}^{+} and S_{rh}^{-} are the input and output slack variables respectively. The i^{th} input and r^{th} outputs are represented by x_{ij} and y_{rj} for each DMU j. The DMU under evaluation is indicated by *h*. The dual variable is represented by λ_j, θ_h is the efficiency score and ε is a small positive scalar.

3.2.2. Linear Aggregation Methods

Next, to compare the NDEA operationalization of risk mitigation strategies, I apply two common weighting schemes to the same data resulting in two additional measures. The first is an equal weighting scheme commonly used to create factor scores of multi-item measures (Comrey and Lee, 1992). Each item is assumed to contribute equally to the construct so a simple sum is used to form an index of risk mitigation. This provides a baseline case for comparison. Many basic performance measurement analyses used by organization often use such linear aggregation, for example the balance scorecard (Kaplan and Norton, 1992). The second measure utilizes weights derived from CFA analysis of the scales. The item loadings from the CFA are used as weights to generate an index of risk mitigation (DiStefano et al., 2009). The formulation for these measures is a weighted sum shown in equation 2 below.

$$\text{Risk Mitigation score}_j = \sum_{i=1}^{m} \rho_i x_{ji} \qquad (2)$$

where x_{ji} denote the level of risk mitigation strategy i for firm j; ρ_i is the weight for risk mitigation strategy i and equals 1 for the equal case and the item loadings for the CFA case. Risk mitigation scores were calculated for flexibility and redundancy.

3.3. Results

NDEA not only provides a single measure of efficiency collectively for the supply chain as a unit, but also scores for individual stages – supply, process and demand. Figure 7 and 8 show the flexibility and redundancy histograms for the four operationalization's of risk mitigation at the supply, process, and demand levels. The differences between the distributions of these variables are apparent. For both flexibility and redundancy, the linear aggregation based measures are bell shaped and approximately normally distributed (the Shapiro-wilk test confirms this assertion for a majority of the distributions). There is also not an apparent difference between the supply, process, and demand levels for these measures. This is not the case for the NDEA scores. The divisional scores account for the dependence between network components and reveal significant differences between stages of the supply chain in their risk mitigation strategies. The supply stage has a heavier distribution of lower NDEA scores than either the process or demand level for both flexibility and redundancy. For flexibility, the percent of firms on the efficiency frontier is also much less than process and demand. The DEA scores calculated individually for each echelon display a similar distribution patter to the NDEA divisional scores. Despite the similarity, the DEA scores are more evenly distributed than the NDEA scores for flexibility and more heavily distributed in the middle of the range for redundancy.

Figure 7. Flexibility distributions

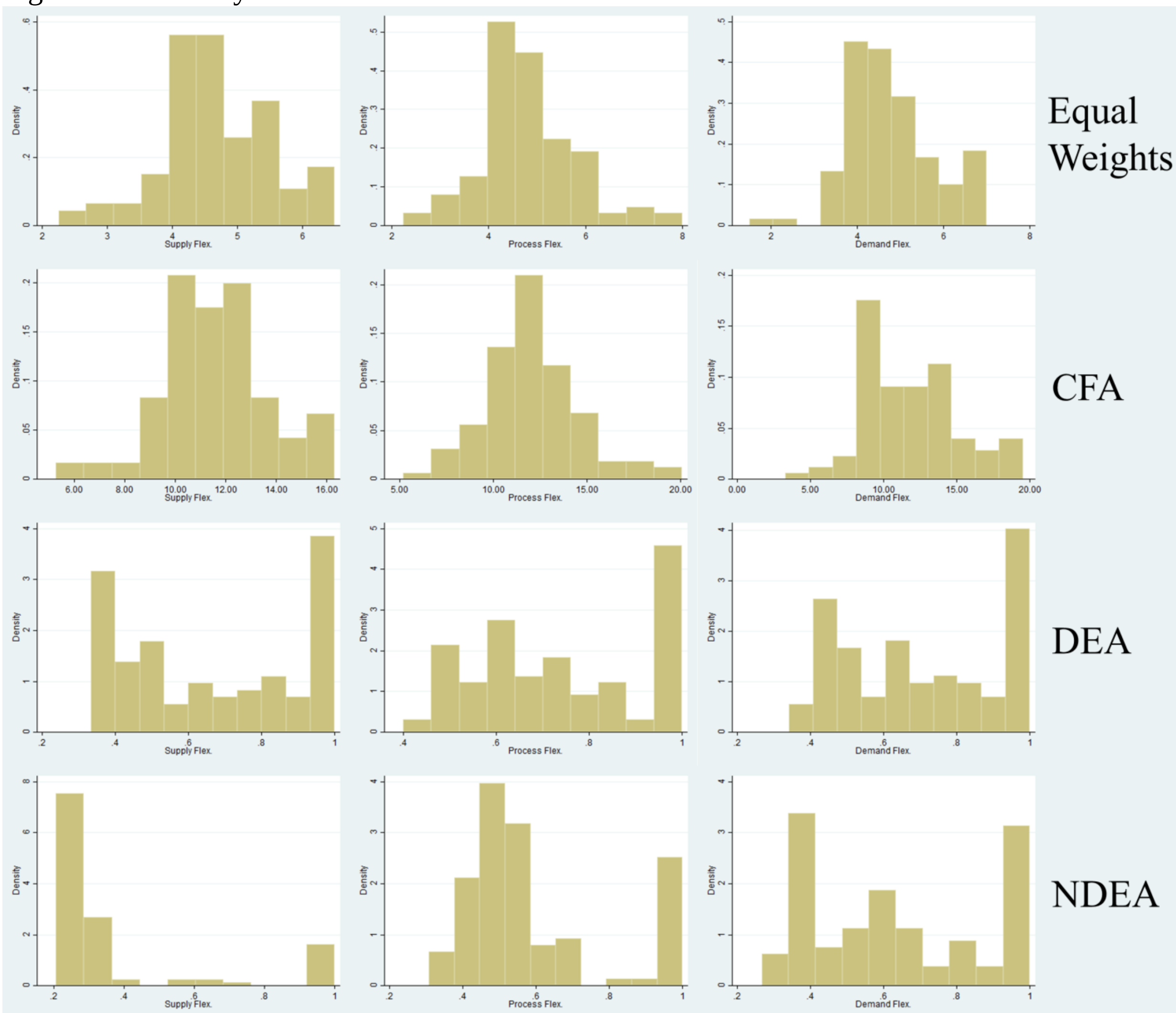
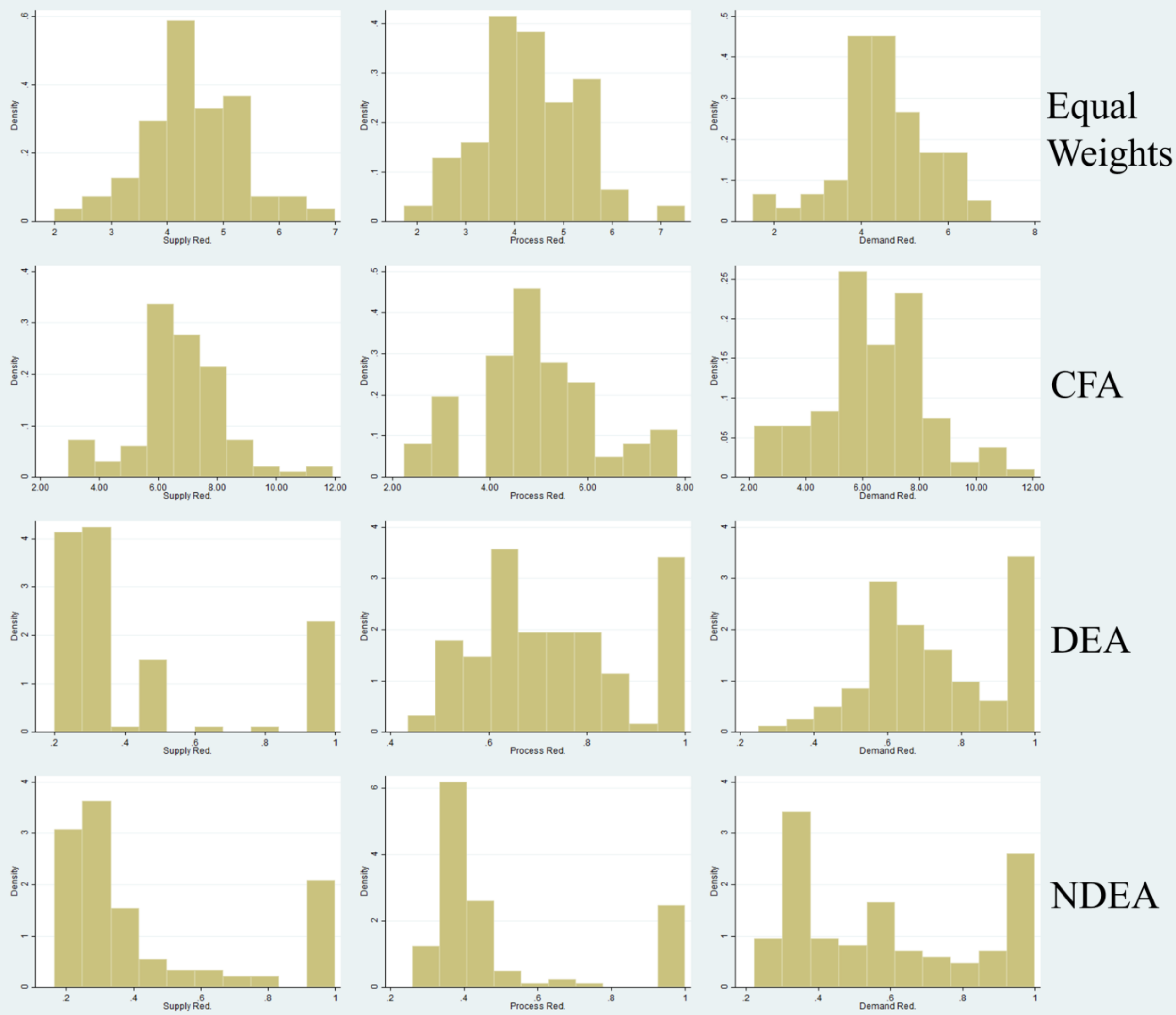


Figure 8. Redundancy distributions

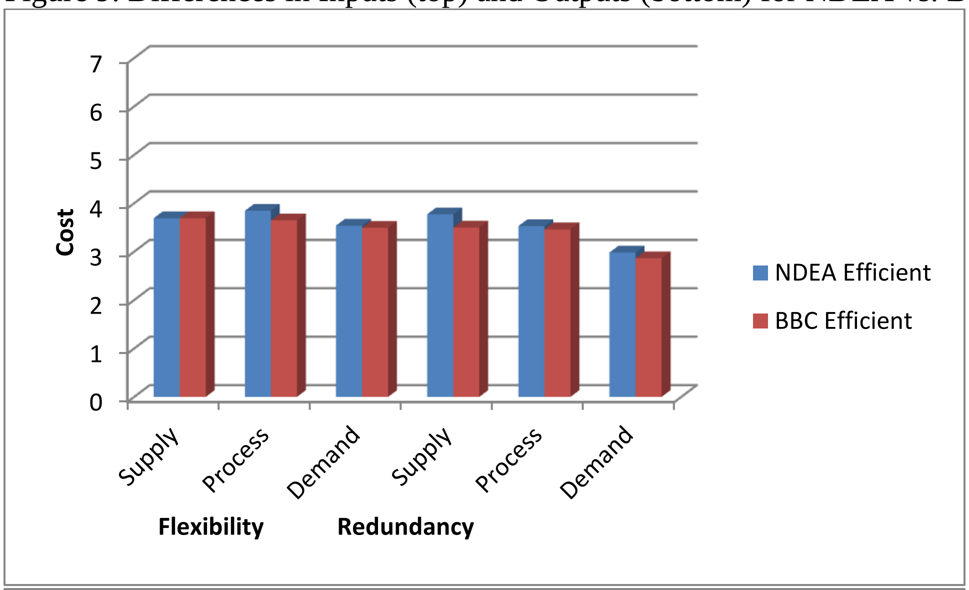


Comparing the difference between distributions statistically supports the observations gained from visually inspecting the histograms. Considering that the DEA based measures are non-normal, I use tests that are robust against non-normality. First, I conducted six pairwise comparisons of the medians and variance for both flexibility and redundancy (12 total). A non-parametric Wilcoxon matched-pairs signed rank test was used to compare the difference in medians. Each test resulted in a rejection of the null hypothesis (at the 1% level), that both distributions are the same. Therefore, the NDEA method creates different distributions for the aggregate scores and DEA score for both flexibility and redundancy using the same data. Next, I compare the equality of variances using the Levene's test. Each pair is statistically significant at the 1% level except the variance of the flexibility NDEA and DEA scores. Based on the results of the Wilcoxon's and Levene's test, the distributions of each method to quantify the performance of risk mitigation systems appear sensitive to the weighting schemes used. This may result in different interpretations of performance and result in inaccurate risk mitigation practices. For instance, a firm may use a simple aggregate performance metric and conclude that their mitigation implementation is acceptable. However, without considering the cost and interdependency among risk mitigation practices, they may be underperforming in reality. This underestimation could even amplify the impact of a disruption by providing a false sense of security.

Given the similarity in methods, comparing the two DEA based measures requires a slightly more detailed investigation. Both provide a method for ascertaining efficiency, yet the NDEA method allows for interdependencies to be explicitly modelled. This results in differences in classification on the efficiency frontier. For instance, 21 firms have an efficiency score of 1 for redundancy and 19 for flexibility using the NDEA score, while only 10 and 8 firms are on the efficiency frontier based for the DEA model, respectively. Each of the firms on the efficiency frontier from the DEA model are also on the efficiency frontier of the NDEA model. Of the firms that are not on the flexibility efficiency frontier in the DEA model, several are among the lower 2/3rds of the sample if I rank order them according to their efficiency scores. This illustrates the loss of information that occurs when interdependencies are ignored. Additionally, the required inputs and corresponding outputs to achieve efficiency vary systematically between the two methods; refer to Figure 9. Inputs are higher and outputs lower to achieve efficiency in the NDEA model, reflecting how efficiency can be achieved by focusing on different aspects of the supply chain. Therefore, the incremental impact of all these factors in a consistent direction does have a significant impact on the efficiency evaluation. Given this, I make the case for considering a holistic measure for supply chain efficiency by incorporating the interactions between various stages via NDEA since traditional DEA underestimates the true nature of efficiency resulting in possible over allocation of resources to improve efficiency and related performance.

From a theoretical standpoint, NDEA permits the modeling of equifinality in achieving an efficient risk mitigation system by considering the interdependencies between stages of the supply chain. Specifically, firms can achieve the frontier by varying mix of investments in supply, process, or demand stages of the supply chain. To illustrate the idea of equifinality, two firms from the sample that both have efficiency scores of 1 are examined, Firm A and B. While both firms had an efficiency score of 1 for both flexibility and redundancy, they achieved it in different ways. This can be illustrated by comparing their raw survey scores to each other and the median of the sample. I see that a firm with an efficiency score of 1 does not necessarily need to have the lowest raw inputs or highest outputs in each domain of risk mitigation. For instance, Firm B’s supply redundancy cost is above the sample median, but was able to achieve efficiency compared to the sample by also having a high degree of supply redundancy. In comparison to Firm A, Firm B has much lower focus on process and demand redundancy, but maintains efficiency through low input cost of these strategies. For flexibility, Firm A has a weakness in supply flexibility while Firm B is poor at converting process flexibility investments to process flexibility. However, each of these firms has a high conversion of inputs to outputs in another domain. Firm B has a higher than median level of supply flexibility with a relatively low corresponding investment. Firm A has higher than median process flexibility and a low input cost of process flexibility. Despite these differences, they are both efficient, displaying how NDEA allows for equifinality in the performance evaluation of risk mitigation strategies. This is important because it also highlights the fundamental premise of considering multiple stages of the supply chain and its interdependencies. Thus, the proposed performance evaluation method allows for the real-life flexibility that managers may have in achieving supply chain efficiency by focusing on different facets of the supply chain.

Figure 9. Differences in Inputs (top) and Outputs (bottom) for NDEA vs. BCC efficient firms



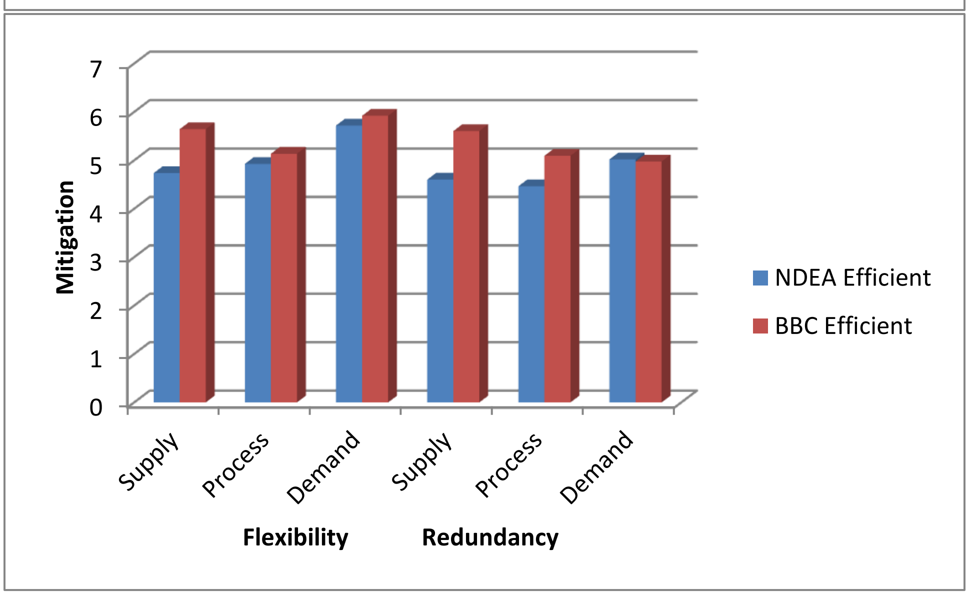
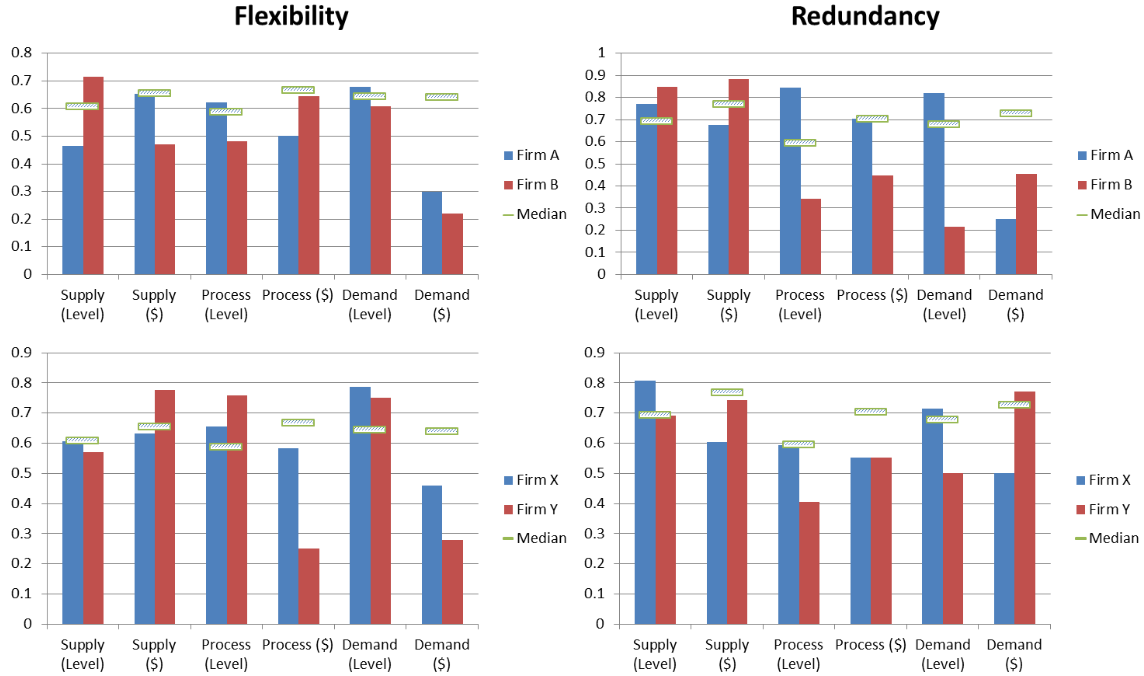


Figure 10. Raw data comparison between firms



Furthermore, the results of the NDEA allows firms that are not on the efficiency frontier to uncover which dimensions each firm may improve upon based on the items from the survey instrument. Take for instance two firms that were not on the efficiency frontier, Firm X & Y. Firm X has an overall score of Redundancy = 0.763 & Flexibility = 0.876 while Firm Y has an overall score of Redundancy = 0.9158 and Flexibility = 0.7621. Not only does it show that Firm X could improve on objectives such as the 'number of product changeovers per manufacturing facility made each month facility' for process flexibility and 'number of alternative/backup suppliers' for supply redundancy; NDEA provides projections for each input, displaying the relative change required to reach efficiency. For instance, the projections show that Firm X must increase the number of backup suppliers 15% or number of product changeovers by 68.8% if it wants to become efficient. These two examples simply represent the questions on the survey instrument, and the performance on any one of the other items may be insightful as well depending on the firm. On the other hand, the NDEA results show that Firm Y could improve its risk mitigation efficiency by reducing a few of its process redundancy costs, such as ‘produce the same products at multiple manufacturing plants’ or ‘maintaining reserved equipment capacity for adverse events.’ In fact, the projections even specify the required change of -2.5 % in time to produce the same product at multiple plants and -30% in time to maintain reserved equipment capacity. While these items were chosen to represent a higher order dimension of flexibility, they are quantifiable activities that a firm could use if conducing a NDEA to evaluate their own risk mitigation system. Items could also be adjusted to reflect the objections of a risk management program tailored to a specific firm. The scores for each of the items are illustrated in Figure 10.

How do firms that are more efficient at mitigating risk perform relative to those that are less efficient? To analyze the impact of using different measures to evaluate performance, I ran an OLS regression on overall firm revenues as a measure of performance. Using revenues allows us to account for the trade-off between the cost of risk mitigation and the impact they may have a reducing risk. A firm that has experience significant disruptions because they did not have a robust risk mitigation system in place would be expected to have lower revenue that a resilient firm. In addition, the cost of investing in risk mitigation strategies may impact revenue negatively. Since the amount of revenue will be higher for larger firms, I control for size and estimate the impact of flexibility and redundancy on firm revenues for each performance evaluation method, refer to Table 20. Size, as expected, is positive and significant in each model. Flexibility quantified using NDEA is positive and significant, while redundancy is insignificant. The CFA based measures are both moderately significant, with flexibility positive and redundancy negative. The equal weight measures for both flexibility and redundancy are insignificant. The DEA score of flexibility is moderately significant and positive while redundancy is insignificant.

While admittedly limited, this analysis displays how differently managers may interpret the same set of risk mitigation strategies simply based on how their performance is evaluated. Revenue provides a financial measure of performance to compare the different quantifications because the objective of any strategy is to improve the bottom line. From a financial performance perspective, the regression results show that flexibility is a valuable strategy. Albeit, quantifying flexibility using CFA or DEA resulted in only moderate significances between financial performance and flexibility. In addition, using CFA may lead to conclude that redundancy strategies reduce financial performance and should be limited. However, from an efficiency perspective they do not have a significant relationship to financial performance and are likely valuable for reducing financial risk if such a measure was available. Overall, the NDEA analysis provides the most powerful model for managers to base decisions concerning resource allocation of risk mitigation that may have an impact on financial performance.

3.4. Robustness Check

While the OLS results show discrimination between the measures, they assume a linear relationship between the covariates and outcome. However, the DEA and NDEA scores are highly skewed and past research has argued that when DEA scores are used as independent variables they are more appropriate as categorical variable rather than continuous (Jacobs et al., 2016; Swink et al., 2006). Thus, I expand upon the first analysis by classifying the firms into three categories: Efficient, Tier 2, and inefficient. Firms were assigned to these groups by quartile for the two linear aggregation measures and based on the efficiency frontier for the NDEA measure following the method of Swink et al. (2006). Firms that were efficient, i.e. have a score of one, were labeled as efficient and removed from the sample. The NDEA and DEA optimizations were recalculated without the efficient firms and those firms who achieved the efficiency frontier on this second analysis were label Tier 2 efficient. The rest of the firms were assigned to the inefficient group. Table 21 present the results of this analysis. The results are consistent for the NDEA measure; high flexibility is significantly positively associated with firm revenue while redundancy is insignificant. Conducting an exploratory test between the impact of efficient and tier 2 firms on performance is insignificant. The results from the continuous analysis do not hold for the CFA measure when firms are categorized. The DEA score of flexibility is again marginally significant and positive, but only for the efficient firms, not the Tier 2 firms.

Table 20. OLS regression - Continuous

	Equal Weights (E.W.)			CFA			DEA					
Revenue	β		Std. Err.	β		Std. Err.	β		Std. Err.	β		Std. Err.
Constant	3.531	+	2.010	5.067	*	2.091	4.499	**	1.314	3.021	+	1.739
Size	0.666	**	0.089	0.634	**	0.092	0.648	**	0.090	0.653	**	0.088
Flexibility	0.473		0.382	0.229	+	0.117	2.296	*	1.002	2.862	+	1.565
Redundancy	-0.056		0.299	-0.326	+	0.173	-0.078		0.956	0.763		1.647
N	108			108			108					
R^2	39.30%			37.50%			38.50%		36.45%			

Table 21. OLS regression - Categorical

Revenue	Equal Weights (E.W.) β		Std. Err.	CFA β		Std. Err.	NDEA β		Std. Err.	DEA β		Std. Err.
Constant	5.055	**	1.109	5.244	**	1.243	5.381	**	1.146	4.594	**	1.246
Size	0.670	**	0.090	0.672	**	0.095	0.634	**	0.092	0.647	**	0.088
Flexibility												
Medium	0.808		0.738	1.118		0.735	1.127	*	0.521	1.136		0.819
High	0.887		0.747	0.725		0.677	1.352	*	0.656	1.488	+	0.775
Redundancy												
Medium	-0.412		0.691	-0.640		0.720	-0.065		0.729	-0.081		0.859
High	-0.351		0.764	-0.857		0.702	-0.323		0.571	0.527		0.804
N	108			108			108			108		
R^2	35.30%			36.20%			36.30%			37.90%		

4. Discussion

This study highlights the importance and difficulty in accounting for the cost of risk mitigation and interdependency in risk mitigation strategies across the supply chain. This study is the first empirical study to incorporate the cost and interdependency of supply chain risk mitigation strategies when measuring and evaluating them. A NDEA method was proposed to address these concerns and the financial implications were displayed in contrast to several other methods. Regression analyses showed that NDEA provides a more powerful and comprehensive perspective on risk mitigation performance across the supply chain. As an optimization model, NDEA allows for the tradeoff between the cost and level of risk mitigation strategies to be quantified explicitly. The study of risk mitigation using NDEA is particularly important because it allows for equifinality in assessing a set of risk mitigation strategies. This follows several scholars emphasis on the importance of accounting for specific exposures and capability of each firm to mitigation risk (Chopra and Sodhi, 2004).

Flexibility and redundancy are both common methods for reducing risk occurring along the supply chain. This study displayed the relative impact each have on financial performance.

Flexibility had a significant positive association with financial performance while redundancy did not. When cost efficiency of the strategies was not considered, redundancies had a negative relationship to financial performance. This result could be expected without considering cost since they are an investment and thus effective only if a disruption occurs. However, when resources are efficiently allocated toward redundant risk mitigation strategies, their negative impact on financial performance disappears. Thus, it appears that flexibility has more than a risk reducing impact, while redundancy is primarily an investment in case a disruption occurs. The literature has argued for the advantages of each, and both are likely needed to obtain a resilient supply chain. Although, flexibility appears to be the better of the two because of its positive relationship to financial performance.

This study also stresses that risk mitigation practices should not be viewed in isolation since the supply chain requires cohesiveness in order to ensure business continuity. A supply chain is dependent on each element within it to operate smoothly. Comparing the DEA and NDEA scores displays how the interdependent nature of risk mitigation strategies can significantly change the perceived performance of them. Without linking the entire risk management program together, interpretation of the program may be incorrect which could have harmful consequences for a firm.

4.1. Limitations & Managerial Implications

This study was limited in several ways which presents opportunity for improvement in future research. First, data was collected via a survey, limiting the scale of measurement and potentially introducing measurement error. Secondary data across firms on levels and costs of specific risk mitigation practices is not available as far as I am aware. However, surveys were deemed appropriate since it was the only source of data available and are often used internally for performance evaluation, for example using balance scorecards (Kaplan and Norton, 1996). Secondly, NDEA analyses only provide relative scores so is sensitive to the addition of DMUs that may be more efficient that those in the sample. While this is not a major concern empirically in this study because I have a single sample, it may limit the generalizability of the results and must be acknowledged if applying NDEA to other samples. Finally, using survey data as an input is not ideal for DEA because the scales are ordinal. While I use a 7 point scale to make the scale approximate continuous, ordinal linear optimization methods applied to NDEA may permit improved optimization (Cook and Zhu, 2006). Unfortunately, there has not been a NDEA model developed that permits the adaption of the method to ordinal data.

Evaluating the performance of strategic initiatives has been shown to be a key to achieving financial performance (Ittner and Larcker, 2003). An important aspect of performance evaluation is measurement and quantification of those measures since this data is what assists the strategic decision making process. As most managers are aware, building risk mitigation systems is not about just implanting risk mitigation strategies, but doing so efficiently. Thus, the measurement of risk mitigation must assess both the degree of risk mitigation and the cost of implementing them. Accounting for both of these dimensions can be accomplished using NDEA. In addition, the entire risk mitigation program must be implemented holistically with the understanding that the different components of operations and supply chain management are intimately linked. The effectiveness and efficiency of a risk mitigation strategy in one area of supply chain risk management may influence other areas. Acknowledging this interdependence can improve the creation and adaptation of mitigating risks. I displayed a method of risk mitigation performance evaluation that accounts both interdependences and investment costs through a novel NDEA analysis.

NDEA is a versatile tool that allows managers to assess the efficiency of their risk mitigation system in relation to other units, divisions, or firms while accounting for the equifinality in achieving a resilient supply chain. While not necessary, weights can also be assigned to different divisions in the optimization to allow for managers to provide additional input in to the model. I displayed the NDEA method for quantifying the efficiency of two general types of risk mitigation strategies: flexibility and redundancy. Flexibility and redundancy function in different ways to reduce the impact of a disruption. According to the analysis, flexible risk mitigation strategies may act as more than simply insurance since financial performance was shown to be significantly related to them and not redundancy. Redundancies are necessary for most supply chains, but due to the high cost of them are not associated with financial performance. I hope that managers can take advantage of my statistical analysis and example of performance evaluation using NDEA to improve their risk management programs and the resilience of their companies.

Chapter 5 - Conclusion

I examine the effectiveness of risk mitigation strategies in the three essays of this dissertation. In the first, I show that exploration and exploitation alliance reduce the rate of failure at different stages in new product development and that this rate is contingent on the diversity of alliance partners. This essay emphasized the role external partners play in reducing risk, building to the next essay of developing risk scales and exploring the differences culture plays in how risks are mitigated and perceived. Finally, the last study applies a performance measurement system that accounts for the interdependencies of risk mitigation strategies throughout the supply chain. Overall, this dissertation investigates the role alliance partners have in new product development, how to effectively leverage them to mitigate risk, and why it is imperative to understand the various perspectives partners may have in managing risk.

Multiple methodologies were used in this dissertation. A survival analysis model was tested empirically from a combination of secondary data sources. Results from this study may help improve the structure and valuation of strategic alliances in the pharmaceutical industry. In the second and third essays, a survey was developed and distributed to three countries. The second essay compares survey data from three countries to explore how different risk mitigation strategies are adopted and supply chain risks are perceived. Measurement invariance tests were conducted using SEM, then country level differences were tested using GSEM. This study enumerates differences in risk mitigation that may improve the coordination of risk management between international firms. In the final essay, I used the data acquired from the USA to develop a performance evaluation tool using NDEA. NDEA is a linear optimization technique that allows for the interdependencies of risk mitigation and the cost of them to be accounted for. This study may improve the performance measurement of risk mitigation strategies and the resource allocation of them for manufacturing firms.

This dissertation integrates risk management at different levels of strategic decision making and a broad perspective of the value chain to contribute to the literature on supply chain risk management (SCRM). A review by Tang (2006) highlights the isolation of research across different areas of SCRM. I attempt to integrate risk management research through a survey instrument and performance measurement tool that account for upstream, internal and downstream practices. Barnes (1984) contend that strategic decisions must account for various biases. I observe that cultural biases are associated with differences in risk perception and mitigation adoption. This result has implications for decision making at a tactical level and in allocating resources between types of slack across the value chain. Lastly, alliance partnerships are an important and necessary strategic decision (Das and Tang, 1998; Baum et al., 2000) that have implications for risk management. I contribute to the literature by displaying in which phase of development different forms of alliances are most effective and the types of alliance partner characteristics are most strongly related to risk reduction in new product development.

Risk threatens supply chains in many different ways and not mitigating them effectively can cost firms millions of dollars. Thus, it is vital that firms have a better understanding of the methods they can use to mitigate risk and the importance of coordination with external supply partners. This dissertation provides a step in improving our knowledge base on supply chain risk mitigation, which will hopefully lead to more research in this domain and an improvement in how risk is mitigated in practice.

APPENDIX

APPENDIX

Survey Instrument

1. Approximately how many employees work for the company? ____________________________

2. What were the company's sales last year? (Millions) ____________________________total sales

3. How many product families does your firm produce? ___________________________________

4. How many manufacturing plants does your firm own?___________________________________

5. Do you have broad experience and knowledge of supply chain operations?_______Yes______No
6. What is your job title?____
7. How many years have you been at your current position?___________________________(years)
8. How many years of total work experience do you have?____________________________(years)
9. How similar are your <u>manufacturing plants</u> in terms of:

a. Manufacturing technologies?

Very similar *Very different*

1 2 3 4 5 6 7

b. Operational practices and protocols?

Very similar *Very different*

1 2 3 4 5 6 7

10. How many regions are your firms manufacturing facilities located? ___# countries__# continents
11. How many outlets does your firm supply across all regions?______________________________
12. How similar are your <u>customers</u> in terms of:

a. Delivery speed requirements?

Very similar *Very different*

1 2 3 4 5 6 7

b. Product quality requirements?

Very different *Very different*

1 2 3 4 5 6 7

13. How many markets does your firm operate in? __________# countries___________# continents
14. How many suppliers are in your supply base (defined as suppliers that are actively managed through contracts and the purchase of parts, materials and services)?_______________________
15. What percentage of your suppliers do you know actively manage supply chain risks?_________%

16. How similar are your suppliers in terms of:

a. Products that they produce?

Very similar *Very different*

1 2 3 4 5 6 7

b. Operational practices and protocols?

Very different *Very different*

1 2 3 4 5 6 7

17. How many locations does your firm source from? ________# countries___________# continents

Please indicate the average level of the following characteristics associated with your firm relative to your competition (Circle a number for each factor with 1 standing for low and 7 standing for high)

	Low *High*
Extent to which your supplier lead-time can be expedited/changed	1 2 3 4 5 6 7
Extent to which your supplier short-term capacity can be increased or decreased	1 2 3 4 5 6 7
Extent of flexibility (options) within supplier contracts	1 2 3 4 5 6 7
Extent to which share of supplied components can be reallocated between suppliers	1 2 3 4 5 6 7
Range of products manufactured by your firms' plants	1 2 3 4 5 6 7
Number of products that each manufacturing facility can produce (average)	1 2 3 4 5 6 7
Number of product changeovers per manufacturing facility made each month	1 2 3 4 5 6 7
Range of production volumes across which manufacturing can accommodate	1 2 3 4 5 6 7
Number of carriers used for each type of delivery mode, on average	1 2 3 4 5 6 7
Number of items handled by each distribution facility, on average	1 2 3 4 5 6 7
Number of items per order handled by each distribution facility on average	1 2 3 4 5 6 7
Number of customers supported by each distribution facility on average	1 2 3 4 5 6 7
Amount of inventory held by your manufacturing plants to manage supply risks	1 2 3 4 5 6 7
Priority in stocking inventory from suppliers	1 2 3 4 5 6 7
Amount of inventory held by your warehouses to meet demand requirements	1 2 3 4 5 6 7
Amount of capacity reserved by your suppliers in case of changes in requirements	1 2 3 4 5 6 7
Amount of capacity reserved in case of sudden changes in demand	1 2 3 4 5 6 7
Please answer this item with a one	1 2 3 4 5 6 7
Amount of space reserved in warehouses in case of sudden changes in demand	1 2 3 4 5 6 7
Number of alternative/backup suppliers selected on a per component basis	1 2 3 4 5 6 7
Number of manufacturing plants that can produce each product (average)	1 2 3 4 5 6 7
Extent to which demand at a specific location can be reassigned to a different location	1 2 3 4 5 6 7
Number of worldwide storage/distribution facilities	1 2 3 4 5 6 7
Suppliers' ability to produce components not currently sourced from them	1 2 3 4 5 6 7
Amount of equipment stored in each plant to produce components not currently produced in that plant	1 2 3 4 5 6 7

Please indicate the average level of cost and time associated with engaging in the following activities in your business unit relative to your competition (Circle a number for each factor with 1 standing for low and 7 standing for high)

	Cost	**Time**
Influence supplier's to increase or decrease short-term capacity	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Change volume allocation among existing suppliers on a global basis	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Change quantity of supplier's order	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Change delivery times of order placed with suppliers	1 2 3 4 5 6 7	1 2 3 4 5 6 7

Change manufacturing volume capacity when necessary	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Accommodate changes in manufacturing mix as required	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Change between producing different products	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Adjust manufacturing processes	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Fills customer orders from individual facilities	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Reallocate logistics services to meet changing customer requirements	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Adjust global delivery capacity	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Reallocate finished product distribution among global storage facilities	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Develop strong relationships with suppliers	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Stock inventory in case of supply chain risk	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Manage multiple sources of supply	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Produce the same products at multiple manufacturing plants	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Maintaining reserved equipment capacity for adverse events	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Improve forecast accuracy	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Reserve space in warehouses for inventory volatility	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Develop options contracts with suppliers	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Duplicate inventory in different locations	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Adjust worldwide storage capacity	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Change supplier of a component to another supplier	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Set up equipment to produce components for the first time in a plant	1 2 3 4 5 6 7	1 2 3 4 5 6 7

Environmental Uncertainty

To what extent has your firm in the past year experienced a negative impact in supply chain management due to… (Circle a number for each factor with 1 standing for "not at all" and 7 standing for "to a very large extent")

	Not at all — *Large extent*
The suppliers consistently meet our requirements	1 2 3 4 5 6 7
The suppliers produce material with consistent quality	1 2 3 4 5 6 7
Our master production schedule has a high percentage of variation	1 2 3 4 5 6 7
Our demand fluctuates drastically from week to week	1 2 3 4 5 6 7
Our supply requirements vary drastically from week to week	1 2 3 4 5 6 7
Our industry is characterized by rapidly changing technology	1 2 3 4 5 6 7
If I don't keep up with the changes in technology, it will be difficult for us to remain competitive	1 2 3 4 5 6 7
The rate of process obsolescence is high in our industry	1 2 3 4 5 6 7
The production technology changes frequently and sufficiently	1 2 3 4 5 6 7

Supply Chain Risk

In this section, please rate the likelihood and severity that the various risk categories pose to your supply chain for one of your most important products or product lines (Circle a number for each risk category with 1 standing for "Low" and 7 standing for "High")

	Low — **High**
Unanticipated or very volatile customer demand	
Likelihood (probability of occurrence)	1 2 3 4 5 6 7
Severity (size of impact)	1 2 3 4 5 6 7
Sudden default of a supplier (e.g., due to bankruptcy)	

Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Poor logistics performance of suppliers (delivery dependability, order fill capacity)
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Supplier quality problems
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Poor logistics performance of logistics service providers
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Insufficient or distorted information from your customers' quantities about orders or demand
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Capacity fluctuation or shortages on the supply markets
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Political instability, war, civil unrest or other socio-political crises
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Disease or epidemics (e.g., SARS, Foot and Mouth Disease)
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Natural disasters (e.g., earthquake, flooding, extreme climate, tsunami)
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

International terror attacks (e.g., 2005 London or 2004 Madrid terror attacks)
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Downtime or loss of own production capacity due to local disruptions (e.g., fire, industrial accidents, etc.)
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Perturbation or breakdown of internal IT infrastructure (e.g., caused by computer viruses, software bugs)
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Loss of own production capacity due to technical reasons (e.g., machine deterioration, poor quality)
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Perturbation or breakdown of external IT infrastructure
Likelihood (probability of occurrence) 1 2 3 4 5 6 7
Severity (size of impact) 1 2 3 4 5 6 7

Technology

Please rate how frequently you use the following Information Technologies (IT): *(Circle a number for each technology; 1=Never, 2=Once in a year, 3=once in a quarter, 4=once in a month, 5=once in a week, 6=once in a day, 7=many times a day)* *Never* *Daily*

Computer aided design manufacturing (CAD) 1 2 3 4 5 6 7
Robotics-automated systems 1 2 3 4 5 6 7
Computer aided manufacturing (CAM) 1 2 3 4 5 6 7
3D images (parts imaging for quality control) 1 2 3 4 5 6 7
Expert production monitoring system 1 2 3 4 5 6 7

Material resource planning systems (MRP I or MRP II) to ensure accurate ordering of materials	1 2 3 4 5 6 7
Electronic data interchange (EDI) with suppliers	1 2 3 4 5 6 7
IT applications (such as desktop sharing) for simultaneously working in real time with external suppliers	1 2 3 4 5 6 7
IT applications for collaborative planning and forecasting of demand with external suppliers (CFAR).	1 2 3 4 5 6 7
IT applications to synchronize production plans across the external suppliers	1 2 3 4 5 6 7
IT applications to share production data (e.g. inventory levels, and production schedules) with vendor managing replenishment systems	1 2 3 4 5 6 7
IT applications (such as analytics or data mining) for creating or changing demand plans	1 2 3 4 5 6 7
IT applications (e.g. Intranet) to acquire marketing information from customers relevant for creating or changing demand plans	1 2 3 4 5 6 7
Bar Coding technologies to acquire customer sales data	1 2 3 4 5 6 7
Radio Frequency Identification Tag (RFID) applications to acquire customer sales data	1 2 3 4 5 6 7
Electronic data interchange (EDI) with clients	1 2 3 4 5 6 7

Financial Performance

For each of the items listed below, how does your company compare with its competitors (*Circle a number*)

	Far Worse Than Competitors				Far Better Than Competitors		
Market share	1	2	3	4	5	6	7
Sales growth	1	2	3	4	5	6	7
Return on Sales (ROS)	1	2	3	4	5	6	7
Return on Investments (ROI)	1	2	3	4	5	6	7
Growth in ROI	1	2	3	4	5	6	7

1. Where is your firm headquartered (Country & City)? ___________________________________

2. What is the primary industry in which your firm operates? _______________________________

3. What year was your firm founded? ____

4. How long has your firm used a systematic supply chain risk program? ___None or ______#years

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