2018

Three Essays on Contagion Risk in Supply Chain

Alireza Azimian
azim9110@mylaurier.ca

Dissertation

Three Essays on Contagion Risk in Supply Chain

Author:
Alireza Azimian
B.Sc. Electronics Engineering, K.N.Toosi,
M.Sc. Nuclear Engineering, Sharif University of Technology,
MBA Commerce, Laurentian University.

Submitted in partial fulfillment of the requirements for

Doctor of Philosophy in Management

At

Lazaridis School of Business and Economics
Wilfrid Laurier University

Dissertation Committee Members:

Dr. Hamid Noori,
Dr. Kevin Hendricks,
Dr. Marc Kilgour,
Dr. Michael Pavlin

Internal/External Committee Member:

Dr. Marc Kilgour

Dissertation External Examiner:

Dr. Constantin Blome

Declaration of Authorship

I, Alireza Azimian, declare that this dissertation titled "Three Essays on Contagion Risk in Supply Chain" and the work presented in it are my own. Confirm that:

- ☐ This work was done wholly or mainly while in candidature for a Doctoral degree at Wilfrid Laurier University.
- ☐ Where any part of this dissertation has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- ☐ Where I have consulted the published work of others, this is always clearly attributed.
- ☐ Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this dissertation is entirely my own work.
- ☐ I have acknowledged all main sources of help.

Signed: ………………………………………………….

Date: December 21, 2017

Acknowledgements

I would like to express my sincere gratitude to Dr. Hamid Noori, Dr. Kevin Hendricks and Dr. Marc Kilgour for their insightful feedback, supervision, and encouragement. In addition, I am indebted to my dissertation committee member Michael Pavlin for his guidance, insightful comments and support over the dissertation process. Also, I am grateful to the Laurier ODS faculty and my fellow PhD students for their feedback and support.

I am thankful to Dr. Constantin Blome, who generously accepted the role of external examiner, for his many helpful comments and insightful recommendations on all three essays, and sincere encouragement. I am grateful to Dr. Shohini Ghose for acting as the chair at my dissertation defence.

I dedicate this dissertation to my beloved wife for her unconditional love, never-ending support throughout this process.

Thank you!

Contents

Chapter 1. Introduction and Overview 1

1.1. Introduction 1

1.2. Dissertation Overview 6

Chapter 2. Dynamics of Contagion Risk 9

2.1. Introduction 9

2.2. Contagion process 11

2.2.1. Theoretical framework 13

2.2.2. Signal value of event 15

2.2.3. Similarities between the liable rival and the firm 17

2.2.4. Trust in the firm 18

2.2.5. Stakeholder's identity 19

2.2.6. Power of stakeholder 23

2.3. Summary and conclusion 25

2.4. References 29

Chapter 3. Empirical Evidence on Contagion 35

3.1. Introduction 35

3.2. Issues and hypotheses examined 38

3.3. Sample selection procedure and data description 43

3.4. Methodology 46

3.4.1. Event Study 46

3.4.2. Capturing signal value 50

3.5. Results 50

3.6. Implication for managers 55

3.7. Summary and Conclusion 56

3.8. References 58

Chapter 4. Management of Contagion Risk 60

4.1. Introduction 60

4.2. Literature Review 64

4.2.1. Related Streams of Literature 64

4.2.2. Perceived Safety and Objective Safety 67

4.3. Preliminary Analyses 68

4.3.1. Duopoly market structure 69
4.3.2. Modeling contagion risk 70
4.3.3. Impact of investment on perceived safety 73
4.4. Modeling 74
4.4.1. Expected profit of a low-risk firm in the presence of contagion 74
4.4.2. Investment profitability under quantity competition 84
4.4.3. Investment profitability in the presence of a neutral firm 85
4.5. Discussion 86
4.5.1. Triggering Event 87
4.5.2. Approaches to contagion risk management 89
4.6. Summary and Conclusion 90
4.7. References 99
Chapter 5. Conclusions and Implications 102
5.1.1. Summary and conclusion 102
5.1.2. Managerial Implications 104

List of Figures

Figure 1-1: Spillover vs. Contagion 2
Figure 1-2: Sequence of events in the contagion process 3
Figure 1-3: Areas of contagion management risk field 6
Figure 2-1: Sequence of conceptualizing the relationships between the attributes 10
Figure 2-2: Elements involved in the contagion process 12
Figure 2-3: Factors contributing to contagion risk 15
Figure 2-4: Spectrum of stakeholder identity 20
Figure 4-1: Effect of triggering event on the expected profit of a low-risk firm 75
Figure 4-2: Impact of ω, on low-risk firm's threshold price and optimal price 79
Figure 4-3: Impact of the risk of initiating event on threshold price 80
Figure 4-4: Impact of perception adjustment rate (φ) on threshold price 80
Figure 4-5: Impact of discount rate I on low-risk firm's threshold price 82
Figure 4-6: Impact of investment horizon T on low-risk firm's threshold price 83

List of Tables

Table 1-1: Types of contagion..5
Table 3-1: Description of Recall Announcements..45
Table 3-2: List of SIC codes representing meat and toy industry.......................49
Table 3-3: Event Study Results..51
Table 3-4: Primary Effect Regression Analysis Results.................................51
Table 3-5: Predicted Sign of the Coefficients...53
Table 3-6: Secondary Effect Regression Analysis Results...............................54

List of Appendices

Appendix 4-1..94
Appendix 4-2..95
Appendix 4-3..98

Chapter 1. Introduction and Overview

1.1. Introduction

In 2015, the market reacted negatively to aviation stocks after a Germanwings pilot deliberately crashed an aircraft with 150 people on board into the French Alps (Welle, 2015). This shows that firms do not always benefit from their rivals' failures and that a failure can sometimes adversely affect an entire industry. Called the "contagion effect", or in short, "contagion", this phenomenon has attracted considerable interest in research about financial crises and how effects spread through company networks. The concept of contagion was first used in the financial economics field by David Ricardo in 1797, who witnessed a panic leading to the suspension of deposit withdrawals by the Bank of England (Kelly and Grada, 2000). However, "contagion" became a common term after July 1997, when it was used to describe the rapid spread of a financial crisis that began in Thailand, moving throughout East Asia and then on to Russia and Brazil (Claessens and Forbes, 2001).

There is no universally accepted definition of contagion in the literature;[1] however, in general, contagion refers to the spread of an effect or behavior throughout a network. In this paper, contagion means the propagation of adverse consequences of a firm's failure to the other firms in the same industry. Given this definition, contagion can also be called the "secondary effect", as opposed to the "primary effect", which refers to an event's impact on

[1] Forbes and Rigobon (2002) consider that contagion is only true contagion if there is no dependence between the markets prior to the shock. In this case, contagion is a pronounced increase in the dependence of the markets. Bekaert, Harvey and Ng (2005) consider that contagion can be described as an excess of correlation between markets, more than it can be explained by economic fundamentals. Corsetti, Pericoli and Sbracia (2005) regard contagion as a break in the parameters governing the correlation system. Kaminsky, Reinhart and Vegh (2003) define contagion as the instant effect following a shock that progresses rapidly between the markets. According to this approach, if the propagation is gradual to the other markets, episodes cannot be regarded as contagion, but as a spillover episode.

the liable firm. Like other risks, contagion risk can be measured either by its probability or by the combination of its probability and impact.

Contagion is different from spillover. Spillover happens when an effect automatically spreads to other firms through fundamental links, whereas contagion occurs when the impact involves judgment and decision making and spreads through behavioral or social mechanisms. For example, when two firms share a supplier, one firm's failure can distress the supplier's operations. When the supplier's operational distress automatically leads to a supply disruption for the second firm, the effect is called spillover. However, when the supplier decides to suspend or terminate the supply to the second firm, the effect is called contagion (see Figure 1-1).

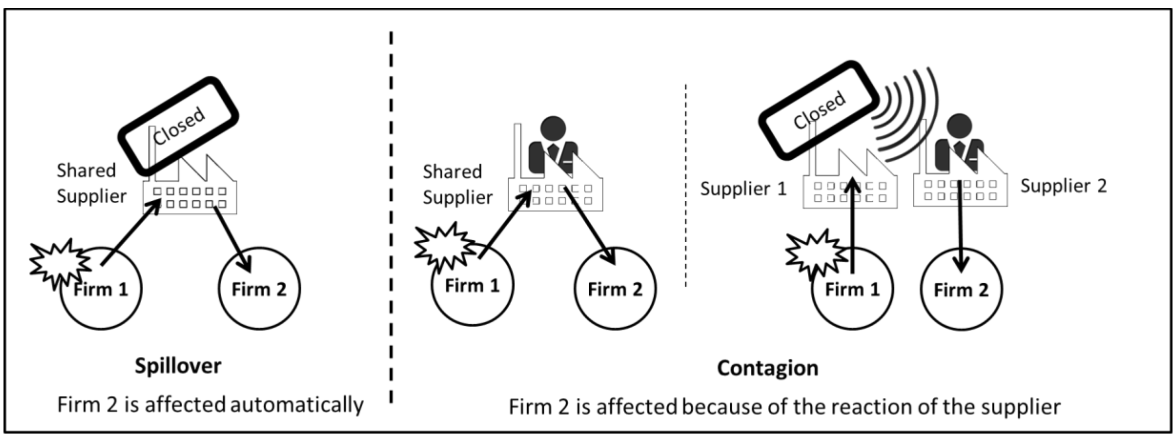

Figure 1-1: Spillover vs. Contagion

The scope of contagion can vary from a specific sector of the economy (sectoral contagion) limited to a particular industry (e.g., the Three Mile Island nuclear accident in 1979)[2], geographical region (e.g., Toyota's acceleration pedal recall in 2009)[3], or market

[2] The accident crystallized anti-nuclear safety concerns among activists and the general public, resulted in new regulations for the nuclear industry, and has been cited as a contributor to the decline of a new reactor construction program that was already underway in the 1970s (Severnini, 2017).

(e.g., the U.S. mad cow crisis in 2003)[4], to an entire economy (e.g., September 11, 2001 terrorist attacks).

Beyond operational failure, contagion can also happen because of an operational breach. For example, Volkswagen's software manipulation of diesel vehicles resulted in an emission scandal that caused the market to react to other German automobile manufacturers (Trefis, 2015). In this study, "failure" refers to both operational failure and operational breach.

Contagion is generated by a triggering event which, in turn, is caused by an initiating event (Figure 1-2). For example, the Fukushima Nuclear disaster in 2011 involved a tsunami (an initiating event) that caused explosions (a triggering event), which ultimately led to the shutdown of all nuclear power plants in Japan (a contagion effect). This distinction is very important from the risk management perspective, because initiation events are difficult to control, while triggering events are generally controllable.

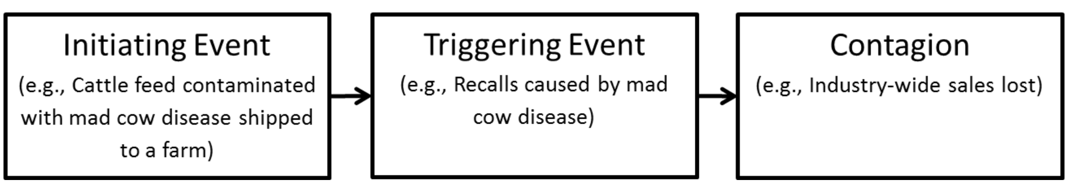

Figure 1-2: Sequence of events in the contagion process

Since the triggering event is subject to the initiating event, the probability of contagion is ultimately characterized by the initiating event. If the probability of the initiating event is

[3] A survey conducted on Toyota's accelerator pedal problem in 2009 showed that the public connected only Asian automakers with the problem (Automotive News, 2010).

[4] U.S. ranchers and processors lost almost $11 billion in revenue between 2004 and 2007 after major importers barred U.S. beef following the discovery of mad cow disease in the United States (Doering, 2008).

known, the probability of contagion can be determined, and hence the focal firm is in a "risk situation". Otherwise, the firm encounters an "uncertainty situation".[5] The distinction between risk and uncertainty situations may affect the focal firm's decision analysis, but such a distinction will not affect the possibility of identifying the contagion effect, so long as the triggering event can be defined or simply constructed. For example, we know the entire Japanese nuclear power industry will likely be shut down (a contagion effect) if another accident similar to the Fukushima Daiichi disaster (2011) happens, whether or not it is possible to determine the probability of large tsunamis.[6]

The review of contagion cases shows that contagion is manifest in at least three forms: a) demand disruption; b) supply disruption; and c) operating cost increase. The review also shows that there are at least three types of triggering events, i.e., i) product harm events, ii) operating events, and iii) social/environmental events.[7] Depending on the type of the triggering event and the form of contagion manifestation, contagion can be classified into nine types as exhibited in Table 1-1.

As depicted in Figure 1-3, the field of contagion risk management can be divided into four areas, including: 1) contagion analysis, 2) contagion risk assessment, 3) contagion measurement, and 4) contagion risk management strategies. Contagion analysis is mainly

[5] In the literature, the word "risk" has been used to refer to different meanings. The most common uses are: 1) Risk as a threat: "What risks threaten our business?", 2) Risk as probability: "What is the risk of going bankrupt?", and 3) Risk as consequence: "What is the risk of non-compliance with emission regulations?". However, in addition to these meanings, risk is also used to refer to a state. This refers to a situation where the probabilities of the alternatives are known ex-ante or can be reliably estimated. Under this definition, risk contrasts with uncertainty, which refers to a situation where probabilities are not measurable (Knight, 1921).

[6] In the process of risk assessment, managers and decision-makers are sometimes more concerned with the risk associated with a specific case under consideration, and not with the likelihood of the average outcomes that may result from various risk situations.

[7] Sometimes an initiating event can cause multiple simultaneous triggering events. For instance, following a fire on an oil rig in the Gulf of Mexico in 2010, the oil rig sank (operational event) and more than five million barrels of oil spilled into the sea (social event).

about characterizing contagion and understanding the mechanisms of propagation and elements involved in this process.

Table 1-1: Types of contagion

Triggering Event Type	Form of Contagion Manifestation		
	Demand Disruption	**Supply Disruption**	**Operating Cost Increase**
Product-Harm Events	In 2003, following the detection of a single case of mad cow disease on a farm in northern Alberta, international customers stopped buying Canadian beef (Statistics Canada, 2009).	In 2015, after a shipment from India was found to contain a foreign insect, Vietnam stopped importing peanuts from India (VBN, 2015). The failure of an importer to control its shipments disrupted supply to all other importers.	Following the recall of Tylenol painkillers in 1982, the FDA tightened packaging regulations, causing the pharmaceutical industry to lose a total of $8.68 billion (Dowdell et al., 1992).
Operating Events	In 2011, following an accident in a Fukushima nuclear power plant designed by GE, Germany and Switzerland decided to phase out nuclear power entirely, and Italy decided to abandon plans to build new nuclear plants (Kagramanyan, 2012). GE's design failure affected the demand for other technology providers.	Following the crash of two American Airline flights into World Trade Center towers on September 11, 2001, the private insurance market stopped providing insurance coverage for airlines (Kunreuther and Michel-Kerjan, 2004). American Airline's security failure affected the insurance coverage of other airlines.	In 2010, a fire on an oil rig chartered by BP caused insurance premiums for deep water oil exploration to increase (Kollewe, 2010).
Social/ Environmental Events	Following the death of more than 1,000 garment workers in the collapse of the Rana-Plaza building which housed a number of separate garment factories, Disney stopped buying from its Bangladeshi manufacturers, although none of them were associated with the event (Greenhouse, 2014).	The supply of live cattle to Indonesian slaughterhouses was suspended after the Australian government banned live cattle exports to Indonesia because of the mistreatment of animals at some slaughterhouses (Minister for Agriculture, 2011). One slaughterhouse's behavior affected the supply of live cattle to other slaughterhouses.	After the spill of about 5 million barrels of oil into the Gulf of Mexico in 2010, the U.S. government tightened offshore oil and gas regulations, costing the industry hundreds of millions of dollars (Enerknol Research, 2015).

Contagion risk assessment involves developing mathematical methods for formulating probability distribution or evaluating the risk of contagion. In contagion measurement, the focus is on evaluating the impact of certain events happening in certain industries. The aim of studies in this area is to identify the events that can cause contagion in the future. Finally, contagion risk management strategies is about studying and developing different plans and policies that can either mitigate the probability or control the consequences of contagion.

The following section briefly explains how each chapter of the dissertation contributes to the four areas.

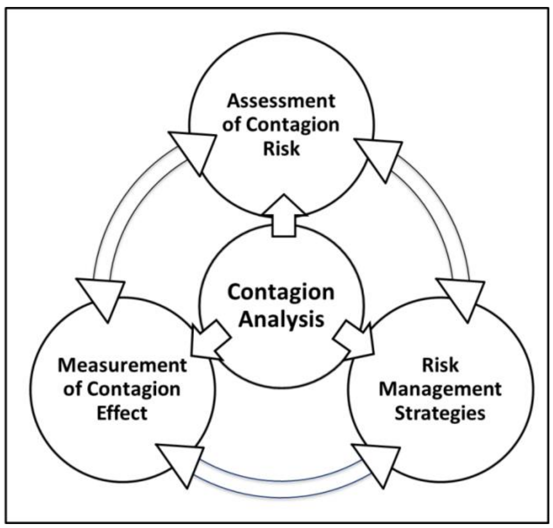

Figure 1-3: Areas of contagion management risk field

1.2. Dissertation Overview

This dissertation is organized into five chapters. This section explains how chapters two to five construct the dissertation.

Chapter 2 aims to build the theoretical foundations needed for chapters three and four and hence contributes to the first area of the field of contagion risk management (Figure 1-

3). Using theories and examples of contagion in different industries, this chapter identifies the elements involved in the contagion process and the key attributes of each element. The chapter provides a brief history of contagion, defines contagion risk, and conceptualizes the contagion process and the relationship between factors contributing to the process, while focusing on the role of stakeholder as the agent of risk. The chapter also explains how a failure of a rival in the industry can cause a firm's stakeholders to react adversely to the firm.

Chapter 3 is founded on the propositions of Chapter 2. The chapter provides empirical evidence on "sectoral contagion" and its relationship to the size of primary effect (impact on the liable rival) and severity of a triggering event as well as its signal value (the factor that causes perceived and actual risks of an event to be different). The study fits into the first type of contagion (see Table 1-1), where the type of event is product-harm and contagion is manifest in the form of demand disruption or reduction. The chapter evidences the role of signal value and introduces a method for operationalizing the construct. The result shows that contagion can occur, even when events are not extreme. Given its results, the chapter contributes to the second and third areas of the field.

Chapter 4 is about contagion risk management and fits into the fourth area of the field. The chapter uses the theoretical model of the contagion process discussed in Chapter 1 and employs economic modeling to find the condition under which investing in the safety of a rival could be profitable. The chapter highlights the difference between actual safety and perceived safety and formulates their relationship.

Finally, Chapter 5 discusses the dissertation's contributions and implications in light of extant research and discusses opportunities for future research. While inter-related, chapters two to four can be read in any order, and readers can consider them as three independent academic essays. Each of the three chapters include an introduction and implications of the research questions, an overview of the related literature, methodology, results, and conclusions. Each chapter’s complete findings are below.

Chapter 2. Dynamics of Contagion Risk

Abstract

Contagion can cause significant loss to non-liable firms. This is a critical issue, especially for firms that over-comply with safety regulations, because they could be penalized for risks that they have already directly addressed, while other firms have not taken appropriate action. Contagion is a serious threat because it can happen even when the triggering event is not severe, or when the liable rival is small. With the goal of enabling low-risk firms to assess and manage contagion risk, I use real cases to conceptualize the contagion process and apply related theories and literature to theorize key factors contributing to contagion risk. I theorize that "stakeholder identity" plays a central role in the emergence of contagion risk.

Keywords: Contagion Risk, Stakeholder Identity, Supply Chain Risk Management,

2.1. Introduction

As mentioned in the first chapter, sometimes one firm’s failure can adversely affect an entire industry. This effect, referred to as "contagion", is a well-recognized concept, especially in the area of financial economics. My search of the term "contagion" in the peer-reviewed financial economic journals returned more than 1,500 results. Contagion has also been studied in marketing in terms of the market reaction to an entire industry following a product recall announcement. A classic example is the Chicago Tylenol murders, where drug tampering in the Chicago metropolitan area in 1982 resulted in a series of deaths. Dowdell and his co-authors (1992) found that major firms in the pharmaceutical industry lost a total of $8.68 billion after the Tylenol recall in 1982. This demonstrates how severe the contagion effect can be. However, what makes contagion an important risk is that it can be triggered by a small event happening to a small firm. For instance, the Canadian mad cow crisis, which cost the Canadian beef industry $7 billion, was initiated by the detection of a single case of mad cow disease that had not even entered the consumption chain. As mentioned in Chapter 1, contagion can manifest itself through demand disruption, supply disruption, or operating cost increases. This implies that contagion risk is a type of supply chain risk, which is caused by rivals. Most of the studies in the area of supply chain management have researched the risks associated either with buyers or suppliers, but to my best knowledge, no study has explored the supply chain risks posed by rivals. This paper attempts to fill this gap by answering the following research questions: (a) How do some adverse consequences spread from a rival to other firms in the same market or industry? (b) What factors contribute to this process? (c) Why do some events have a contagion effect, while others do not? And finally, (d) Why are some industries more susceptible to contagion than others?

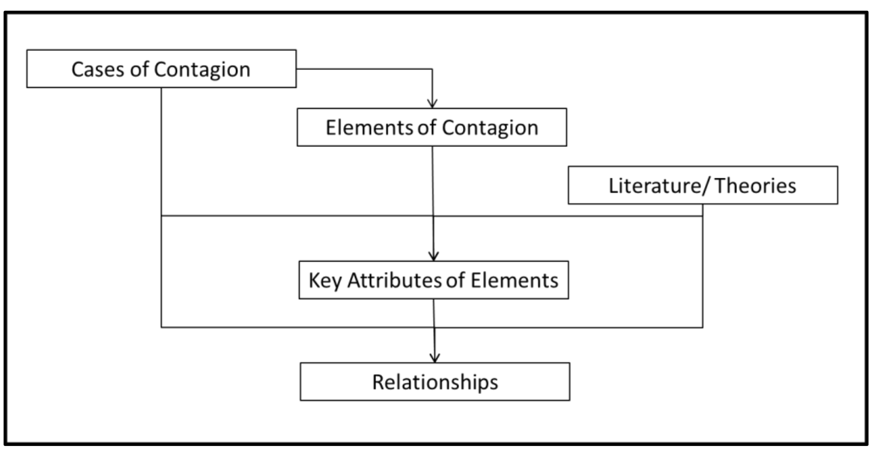

Figure 2-1: Sequence of conceptualizing the relationships between the attributes

To answer these questions, I use existing literature and theories in decision-making, cognitive psychology, and risk management fields, along with supporting examples of adverse events in different supply chains to theorize the key elements involved in the contagion process, the main attributes of the elements, and the relationships between the attributes and contagion (See Figure 1-4).

The chapter sheds new light on the nature of contagion risk by exploring it from a decision-making view, highlighting the role of stakeholders as the agents of risk, and conceptualizing and integrating various types of contagion into a single process model. The next section further discusses the concept and the properties of contagion.

2.2. **Contagion process**

Based on the cases of events I reviewed, at least four key elements are involved in a contagion process (Figure 2-1): (a) triggering event, (b) liable rival, (c) focal firm facing contagion risk, and (d) stakeholder(s) of the focal firm. Stakeholders act as the agents of contagion risk. Therefore, the stakeholder is the center of analysis in this study. Although firms usually have multiple stakeholders, I explore the decision-making process of a single stakeholder to avoid unnecessary complexity. A stakeholder is "any group or individual who can affect or is affected by the achievement of the firm's objectives" (Takeuchi, 2010). Since organizations fundamentally rely on individuals to undertake activities, such as analyzing, assessing, and reacting to risks on its behalf, I use individual-level cognitive theories of risk behavior to theorize the factors contributing to a stakeholder's judgment of risk and decision. As it is cumbersome to simultaneously deal with the individual and corporate meanings of stakeholder, I consider stakeholders as either a group of individuals having one or more characteristics in common (e.g., consumers), or as an organization.

When news spreads about a rival firm's adverse event , stakeholders of every other firm in the industry (re-)evaluate the probability that similar events will occur at their firm. If the re-evaluated risk exceeds an acceptable level, the stakeholder may decide, or be forced by its constituents (the entities that have a legitimate interest in the stakeholder), to modify its relationship with the firm to address their own risk. The modification of the relationship can range from minor changes, such as adding clauses to a contract or decreasing the frequency and size of transactions, to the termination of the relationship.

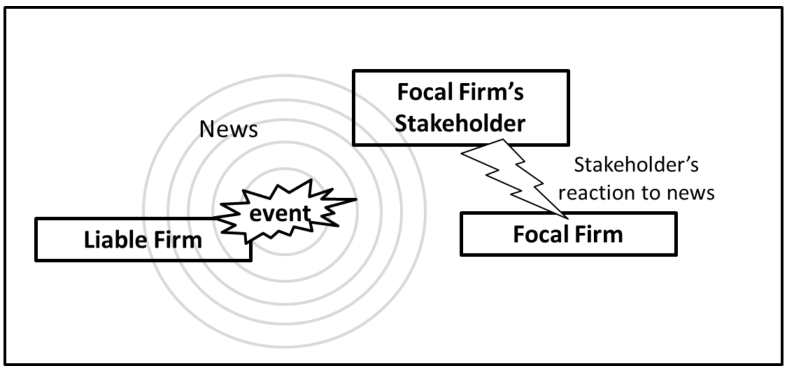

Figure 2-2: Elements involved in the contagion process

A fundamental concept in my study is "risk judgement". Risk judgment could either be objective (actual) or subjective (perceived) (Rowe and Wright, 2001). This dichotomization arose from the observation that experts and laypeople often disagree about the risk level associated with different events (Taylor et al., 2014). An expert is defined as a person with a background in the subject area who is recognized by others as an expert in that area (Skjong and Wentworth, 2001). While objective risks are based on "expert judgments" or "assessments", subjective risks (the degree of uncertainty perceived by individuals) are derived from "lay judgments" or "perceptions". Objective definitions of risk see it as a statistical expectation value of outcome severity. On the other hand, subjective risk is based on “people’s beliefs, attitudes, judgments and feelings, as well as the wider social or cultural values and dispositions that people adopt towards hazards and their benefits” (Pidgeon et al., 1992). Brun (1994) argues that, similar to objective risk, subjective definitions of risk tend to include event severity and uncertainty dimensions, but Slovic (1997) suggests that even if these were the only two dimensions included in lay perceptions, lay risk perception would still differ from expert risk assessments due to heuristics and bias that influence such quantitative estimates.

Risk perception involves collecting, selecting, and interpreting signals about uncertain impacts of events, activities, or technologies (Wachinger et al., 2013). These signals can refer to either direct observation or information obtained from others. Perceived risk varies depending on the type of risk, the risk context, the personality of the individual, and the social context, and is influenced by knowledge, experience, values, attitudes, and feelings (Wachinger et al., 2010).

In this research, an objective judgment process is used to evaluate contagion risk. However, stakeholders evaluate their risks through a process that involves a combination of objective and subjective judgments, depending on the stakeholder’s identity.

Given the elements involved in the contagion process, I theorize the factors contributing to contagion risk and propose a framework illustrated in Figure 2-1.

2.2.1. Theoretical framework

As previously mentioned, a firm’s contagion risk refers to the probability of an adverse reaction of the firm’s stakeholder(s) pertaining to a specific triggering event. By definition, contagion risk is described and measured in association with a certain event or an event type. An adverse event in the industry can stimulate the stakeholder's concern about the occurrence of similar events to the focal firm and drive it to react if the stakeholder concludes that the firm is unable to manage the new state of risk. This suggests that contagion risk has a direct relationship to the change in the stakeholder's judgment of the focal firm's risk, which, in turn, derives from the change of the stakeholder's judgments on:

a) the seriousness of the event,

b) the extent to which the focal firm is prone to similar events, and

c) the ability of the focal firm to manage risk.

An expert stakeholder's judgment of the firm's risk does not change through a single event, unless the event's severity exceeds an estimated maximum threshold (*informative contagion*). However, a lay stakeholder's judgment can be influenced, even if the event is not actually severe (*naive contagion*). The difference lies in their dissimilar approaches (subjective vs. objective) to risk evaluation. A subjective approach to causes a non-frequent event to be perceived as unlikely before it happens and very likely after it. A subjective approach can also cause a firm's exposure to a given event to be overestimated when it is built on superficial similarities between the firm and its rival which has recently been affected by an event. When these distorted judgments are combined with the underestimation of the firm's risk-management capability, they can lead to a severe reaction of the lay stakeholders to the firm. This difference between lay and expert approaches to risk judgment supports the theory that firms are at higher risk of contagion when their stakeholders decide like laypeople. Therefore, this paper explores "naive contagion" and the process and factors that contribute to the misjudgment of risk by lay stakeholders (Figure 2-2).

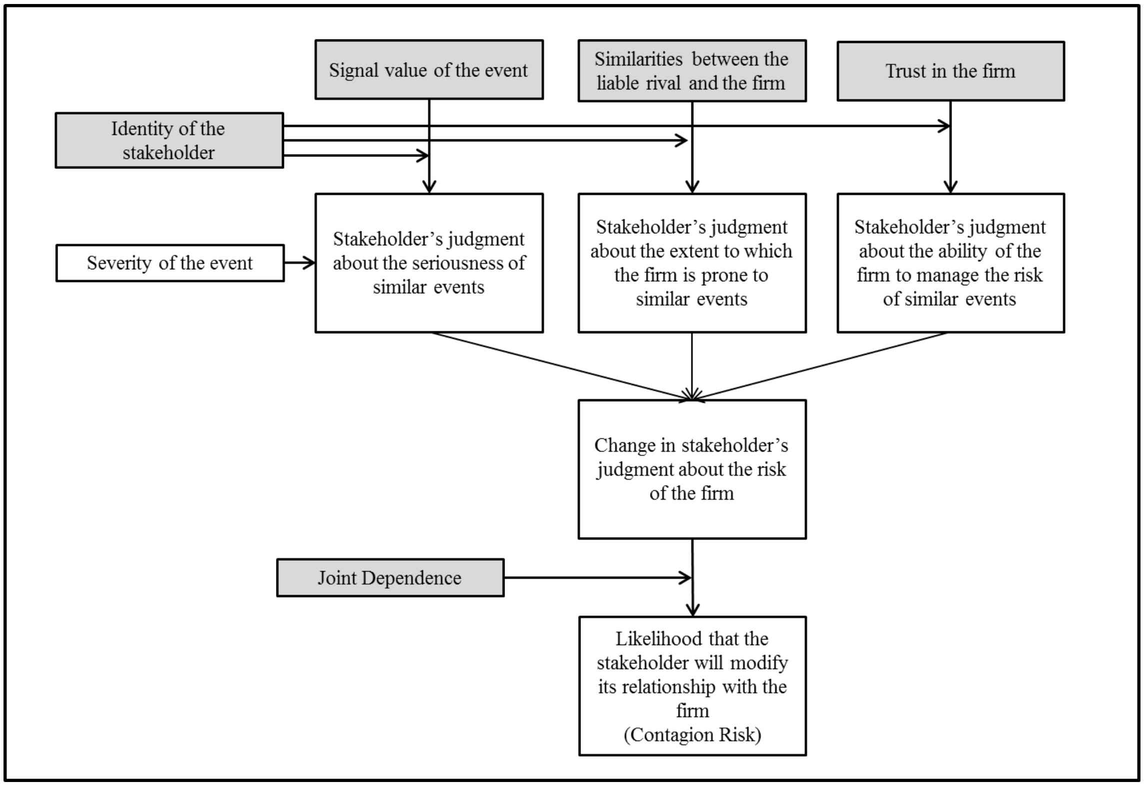

Figure 2-3: Factors contributing to contagion risk

The key attributes of the four elements of contagion, namely event, liable rival, focal firm, and the focal firm's stakeholder, impact a lay stakeholder's judgment of risk. These attributes include (i) signal value (attribute of event), (ii) similarities to the focal firm (attribute of liable rival), (iii) stakeholders' trust (attribute of focal firm), and (iv) identity and power (stakeholder attributes).

2.2.2. Signal value of event

Early theories linked social risk judgments and responses to event severity measured by deaths and casualties and/or cost of damages; however, events such as the Three Mile

Island nuclear accident in 1979 and the mad cow crises in Canada and the U.S. in 2003, which had no fatalities but caused huge social impacts, demonstrate that a property other than "severity" also contributes to the public's perception of the event's seriousness. This property is referred to as "signal value", the degree to which an event increases one's perception of the risk of similar or more destructive events in the future (Slovic, 1987). The process by which risks are intensified by lay stakeholders is explained by the Social Amplification of Risk Framework (Kasperson et al., 1988). According to the framework, a triggering event interacts with psychological, social, and cultural processes in ways that can intensify lay individuals' perceptions of risk and related risk behavior (Kasperson et al., 2005). The signal value of an event is closely related to its perceived lack of control, catastrophic potential, fatal consequences, and the inequitable distribution of risks and benefits, as well as the extent to which its manifestation of harm is unobservable, unknown, new, and delayed in its manifestation of harm (Slovic et al., 1987). Given this explanation, we expect an event such as a train wreck with high fatalities to cause relatively little social disturbance because it occurs as part of a familiar and well-understood system. However, a small event, such as a minor accident with a nuclear reactor, is expected to cause great public concern, as the accident is interpreted to mean that its risk is not well understood, not controllable, or not competently managed. Given the above discussion, I propose the following:

Proposition 1: All other factors remaining unchanged, the higher the signal value of an event, the more likely it is that the event will change stakeholders' judgment of risk.

2.2.3. Similarities between the liable rival and the firm

By definition, lay individuals tend to use heuristics to deal with the full complexity and multitude of risks. Heuristics are simplified mechanisms and mental shortcuts used to evaluate risk and shape responses (Kahneman et al., 1982). One heuristic is the "similarity heuristic", which pertains to how people make judgments based on the similarity between current situations and other situations or situation prototypes. The goal of the similarity heuristic is to maximize productivity through a favorable experience while not repeating an unfavorable experience. This explains why lay individuals tend to use their past experience to shape their world view and incorporate them in their current experiences. Heuristics work well in most conditions; however, they can lead to systematic deviations from logic, probability, or rational choice theory (Tversky and Kahneman, 1985). The resulting errors are referred as "cognitive biases", of which many different types have been documented. Cognitive biases resulting from similarity heuristics include ignoring prior probabilities, assuming that similarity in one aspect leads to similarity in other aspects, and assuming that a small sample is representative of a much larger population (Tversky and Kahneman, 1982). A typical example of these biases is when consumers overestimate the extent that a firm superficially similar to an unsafe rival is prone to the same event that hit the rival, even though the firm is from a population containing relatively safe firms. The similarity of a firm to its rival can lie in its product, process, technology, supply chain, or origin. For instance, in their studies on automobile recalls, Crafton et al. (1981) and Reilly and Hoffer (1983) showed that industry rivals that produce similar lines of cars suffer declines in sales following serious automobile recalls. As another example, a survey conducted on Toyota's accelerator pedal problems in 2009 showed that the public connected other Asian automakers, including Honda, Hyundai, and Nissan, with the problems (Faktenkontor, 2009). In explanation of this finding, an expert argues that in customers' minds, Toyota ranked highest in quality among Asian carmakers, leading them to conclude that other manufacturers with the same origin (Asia) would have even more problems with quality (Automotive News, 2010). I propose the following:

Proposition 2: All other factors remaining unchanged, the higher the similarities between the firm and the liable rival, the more likely it is that an event will change stakeholders' judgment of risk.

2.2.4. Trust in the firm

Almost all types of social relationships, including risk management, rely on trust. In fact, most of the argument in risk management has been related to the existing distrust between the public (lay individuals), industry, and risk management professionals (e.g., Slovic, 1993, Slovic et al., 1991). In order to understand the role of trust, it is helpful to compare the risks lay stakeholders fear and those they do not. Slovic (1990) found that people perceive less risk from medical technologies, which are based on the use of radiation and chemicals (i.e., x-rays and prescription drugs), than industrial technologies involving radiation and chemicals (i.e., nuclear power, pesticides, and industrial chemicals). Although x-rays and prescription drugs pose significant risks, people's relatively high degree of trust in the physicians who manage these devices makes them appear safer. In contrast, numerous polls have demonstrated that government and industry officials who manage nuclear power and nonmedical chemicals are not highly trusted (Cvetkovich, 2013).

Keh and Xie (2008) found that in times of crisis, high levels of trust have the power to increase confidence and decrease perceived danger. Similarly, situational crisis communication theory posits that a history of crises can negatively influence the reputation of and trust in the firm and shape consumers' perceptions of future crises (Coombs and Holladay, 2001, 2002). Seo et al. (2014) found that following the E-Coli outbreak in its restaurants in 2003, Jack in the Box's stock prices showed significantly negative responses to other firms' food crises that occurred from 2004 to 2010.

The role of trust in risk perception may also explain why domestic beef consumption did not decline after the announcement of a single case of mad cow disease in Alberta in 2003 caused international customers to ban Canadian beef; in fact, it increased by more than five per cent (Statistics Canada, 2004). While this could have been related to the drop in domestic beef prices due to the plunge in international demand, consumers would not have risked consuming contaminated beef without having trust in beef suppliers. I propose the following:

Proposition 3: All other factors remaining unchanged, the higher the stakeholder's trust in the focal firm, the less likely it is that an event will change their judgment of risk.

2.2.5. Stakeholder's identity

A stakeholder is a body of lay and expert individuals who evaluate risks and make decisions. As discussed, experts use statistical data, such as annual fatalities, in their assessments of an adverse event's severity, whereas laypeople rely on heuristics and qualitative risk characteristics. These differing methods often result in laypeople assigning relatively little weight to risk assessments conducted by technical experts or government officials (Covello et al., 1987), leading to an overestimation of the severity of a feared event. In reality, experts are prone to many of the same biases and heuristics as those of the general public, especially when they are forced to go beyond the limits of available data and rely on intuition and extrapolation (Kahnemann et al., 1982, Henrion and Fischhoff, 1986). However, they are less likely to make mistakes as a result of these biases, because they employ calculative modes of reasoning (as opposed to intuitive reasoning) more frequently to analyze risks (Ropeik, 2009; Sunstein, 2003). As the percentage of expert decision-makers relative to the total decision-makers in a group of individual stakeholders or in an organization (non-individual stakeholder) varies from zero to one hundred, the "identity" of a stakeholder can vary along a spectrum from "absolute-lay" to "absolute-expert" (Figure 2-4).

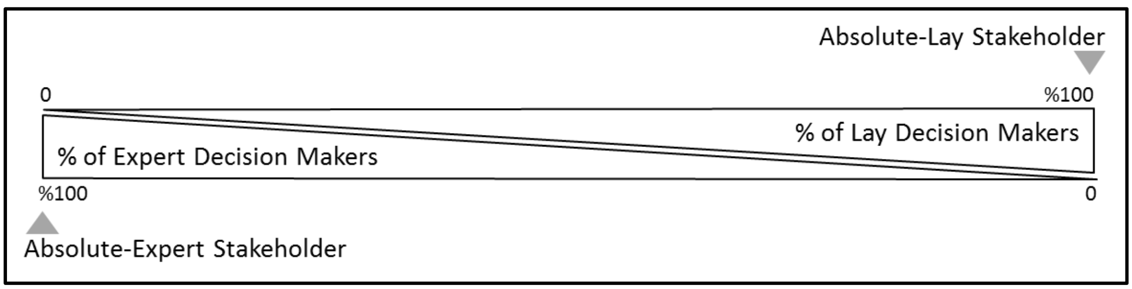

Figure 2-4: Spectrum of stakeholder identity

I define the "identity of a stakeholder" as the extent to which a stakeholder relies on the judgment of experts, as opposed to laypeople, to evaluate risk and make a decision. The closer the identity of the stakeholder is to absolute-expert, the more the stakeholder will rely on statistical data, while the closer they are to absolute-lay, the more they will rely on qualitative characteristics. As illustrated in Figure 2-2, "signal value of the event", "similarity between the firm and the liable rival", and "trust in the firm" are three main factors that influence absolute-lay stakeholders and can drive them to overestimate the firm's risk. This means that the risk of contagion diminishes as the identity of the stakeholder approaches to absolute-expert.

Thirumalai and Sinha (2011)'s study explored the financial consequences of product recalls in the medical device industry and showed that the market penalties for medical device recalls are not significant. This finding is interesting when compared to the market reaction to recall announcements in other industries, such as food (Thomsen and McKenzie, 2001) and automotive (Jarrell and Peltzman, 1985; Bromiley and Marcus, 1989), where the market's recall penalties are significant. Hospitals and physicians (medical experts) make up a large part of the medical device customer group and are often in direct consultation with device manufacturers (technical experts) in making purchase decisions. Decision making across this group is strongly influenced by the policies of private insurance providers and Medicare/Medicaid, which are also bodies of experts. I argue that the previously mentioned difference in market reaction to medical device recalls is derived from the fact that the identity of the stakeholders involved in purchasing decisions in the medical device industry is closer to absolute-expert than other industries, such as food and automotive, where stakeholders are mainly groups of lay individuals, such as retail consumers. This leads to the following proposition:

Proposition 4: Stakeholder identity moderates the relationship between the change in stakeholders' judgment of risk and signal value of event, similarities between firm and liable rival, and stakeholders' trust in the firm.

For organizational (non-individual) stakeholders such as suppliers, distributors, or governments, identity is also influenced by the collective identity of constituents. Similar to stakeholders, the identity of constituents varies along a spectrum with two extremes of absolute-expert and absolute-lay. Fearful constituents within or outside the value system can put pressure on the stakeholder and influence its judgment of risk. For example, in the Tazreen fire disaster in 2012, a fire broke out in the Tazreen Fashion factory in Dhaka, Bangladesh. At least 117 people died in the fire and over 200 were injured, placing buyers, such as Disney, under intense pressure from consumers at home to address poor workplace safety in Bangladesh. As a result, Disney decided to withdraw operations from Bangladesh (Palmeri and Rupp, 2013). Tazreen was not an authorized supplier for Disney-branded products – neither for independent licensees producing their own product, nor for product sold by Disney through its own retail operations. In fact, what forced Disney to terminate its relationship with suppliers in Bangladesh was pressure from consumers and society (constituents) who perceived a high risk of non-compliance and negative social behavior.

Disaster literature indicates that some industries engage in more mitigation and preparedness than others. For instance, Dahlhamer and D'Souza (1997) found that businesses in the finance, insurance, and real estate industries do more to prepare for disasters than businesses in other industries. Similarly, Drabek (1991, 1995) found that lodging businesses have more extensive disaster evacuation plans than businesses in the food service, entertainment, and travel industries. A plausible explanation could be that prepared industries are more sensitive to risk, and therefore involve more experts in their risk management decisions than other industries. If this is true, stakeholders from risk-sensitive industries are expected to have an identity closer to absolute-expert than stakeholders from industries that are less risk-sensitive. Larger stakeholders have more resources available to hire experts. A higher number of hired experts approximates the identity of a stakeholder to absolute-expert; however, the number of lay constituents generally increases as the size of the stakeholder group grows. Given these two opposite effects, the impact of a stakeholder group's size on its identity is indefinite.

2.2.6. Power of stakeholder

Stakeholders need power to enforce desired changes in their relationship with the firm. There are many different ways of categorizing power as a construct in business research. However, from the source-of-power perspective, power can be classified into six types: reward power, coercive power, legitimate power, referent power, expert power, and informational power (French et al., 1959). The source of power is not mutually exclusive, and a stakeholder and firm may possess more than one power type.

The extent to which a stakeholder can exert its power depends, not only on its own power, but on the power of the firm. Government and regulatory bodies are generally powerful stakeholders; however, their power is weakened when they depend on an industry for information (information power), or when an industry has strong economic bargaining power (coercive power). This was the case in the Jack in the Box E. coli outbreak. The meat industry in the U.S. is a powerful political force, both in the legislative and regulatory arenas, and most of the companies involved in the meat business are represented by one or more of the powerful meat trade and lobbying organizations. In 1995, the United States Department of Agriculture proposed implementing new food safety regulations in response to the Jack in the Box E. Coli outbreak that made hundreds of people sick. As discussed, new regulations can cause contagion by increasing operational costs of all the firms in the industry. The meat industry succeeded in stopping the implementation of the new regulations, and therefore contagion, by persuading a member of the key appropriations committee to introduce an amendment to prolong the rulemaking process (Johnson, 2015).

Power also emerges through an unequal dependence between stakeholder and firm and could be detrimental for the weaker party (Stolte and Emerson, 1976). However, according to Emerson (1962), an increase in dependence asymmetry could be coupled with a simultaneous increase in the sum of partners' dependencies on each other, which is referred to as "joint dependence". Joint dependence can influence the stakeholder's power derived from unbalanced dependency. According to embeddedness theory, higher levels of joint dependence must increase the depth of economic interaction between partners, building a stronger relational orientation (Uzzi, 1996, 1999). This results in more trust between partners and decreases the risk of power exertion. Following the Tazreen Fashion factory fire disaster in 2012, Disney decided to withdraw from Bangladesh, while other big names, including Walmart, initiated processes to improve factory safety and worker wellbeing. Given that, in both cases, dependence asymmetry favored retailers, the differences in the retailers' reactions can be partially explained by differences in the levels of joint dependence in their relationships with garment manufacturers. This argument is supported by the fact that Walmart's apparel revenue was over $20 billion in 2012 (Souza, 2013), while Disney's total consumer product revenue was less than $4 billion (Statista, 2015). This suggests the following proposition:

Proposition 5: All other factors remaining unchanged, the higher the joint dependence between stakeholder and firm, the less likely it is that a stakeholder will modify its relationship with a firm because of a change in its judgement of risk.

2.3. **Summary and conclusion**

This essay attempts to theorize the contagion process. Building on a survey of adverse events in varying industries and a literature review, I demonstrate how a rival's failure in risk management can unfavorably affect other firms' supply, demand, and operations. Although the scope of the contagion effect in most of the cases discussed in this paper are industry-wide or market-wide, contagion can also occur in small segments of the market or industry. This implies that contagion may be more frequent than we think. A plausible reason that we do not hear much about the latter type of contagion might be that public interest is peaked only by events causing widespread contagion effect. I use relevant literature from psychology, sociology, and management to conceptualize the process of contagion and the contributing factors. I view contagion as a decision-making process and propose that the entities involved in contagion are the event, the liable rival, the focal firm, and the firm's stakeholders. Contagion begins when an adverse event happens to a rival. The event triggers the stakeholder to re-evaluate the risk that a similar event will happen to the focal firm. If the evaluated risk exceeds an acceptable level, the stakeholder may modify its relationship with the firm to address the risk.

Building on the literature about the differences between the approach of laypeople and experts to risk judgment (assessment vs. perception) and biases embedded in risk perception, I introduce the notion of "stakeholder identity". I contend that a stakeholder's judgment on the focal firm's risk is more likely to be realistic when it has a closer identity to absolute-expert. Identity is based on the degree to which a stakeholder's judgment of risk is objective as opposed to subjective. I suggest that the closer the identity of the stakeholder is to absolute-lay, the more its judgments and subsequent decisions will be based on biased measures including (a) signal value of the event, (b) similarity between the focal firm and the liable rival, and (c) trust in the focal firm's risk management.

I also highlight the role of the stakeholder's power in the risk of contagion. I refer to power as the ability to enforce desired changes in the relationships for stakeholders. I argue that the relative power of a stakeholder diminishes as the power of the firm increases, and discuss some of the conditions in which this may happen. For example, the approach to regulating the industry can affect the power of government and regulatory authorities. When an industry is self-regulated and has bargaining power, there is a greater chance that the industry can block or postpone legislation processes, thereby limiting the risk of contagion. Dependence asymmetry in favor of a business partner, as a stakeholder, increases stakeholders' power, but joint dependence (the sum of partners' dependencies on each other) diminishes it. Therefore, the risk of contagion is higher when the joint dependency is weaker.

A focal firm can estimate the potential signal value of a certain event from its position on the "Dread risk – Unknown risk" factor space to estimate the risk of contagion. The chance that the focal firm will resemble a liable rival can be measured by the industry's commoditization level. The trust of the stakeholder in the focal firm's risk management competence and power balance between the stakeholder and the focal firm can be assessed from the history of their interactions. Although it is beyond the scope of this paper, how to measure the identity of a stakeholder is an important and interesting research question.

I discussed two reactive and two proactive strategies to manage contagion risk. I explained how lobbying and publicizing can address the threat of tighter regulations and supply or demand disruption. I also discussed how self-regulating and investment in the safety of high-risk rivals can prevent the probability of contagion.

In summary, I have identified a new research direction that can generate novel research questions on risk management in supply chain management. Specifically, I introduce the notions of contagion risk and “stakeholder identity”, conceptualize the factors influencing contagion risk, highlight the underlying role of stakeholder as the agent of contagion risk, and classify contagion risk according to the type of triggering event and form of contagion manifestation (see Table 1-1). On the practical side, my findings help risk managers design more effective risk management strategies in supply chain by integrating the risks that are imposed by rivals. The results derived from my research has important implications for supply chain and operations management scholarship, in that it explores contagion risk in the context of decision making processes, highlights the role of stakeholders as agents of risk, and conceptualizes and integrates various types of contagion into a single process model.

A limitation of my research is that it is multi-layered and multi-theoretic and draws theories from multiple disciplines, making it challenging for the audience. I understand that going deeper into the various propositions in separate papers would help to address it; however, this is not possible before integrating the concepts, supporting theories, information, and terminology in one piece to build the foundations needed for further research. Contagion, as a whole, is a coherent concept and its components are best understood in context and in relation to one another.

Testing these theories using empirical methods is a natural direction for the future extension of this research. This can be done separately for each of nine different types of contagion risk discussed above. The main challenge in this direction is operationalizing the construct of "stakeholder identity". The other direction for future research is to measure contagion risk. This involves a combination of analytical and empirical approaches to formulate and test the risk. The result of the research can then be used to develop an insurance policy for contagion risk.

2.4. **References**

Automotive News. (2010). *Asian rivals suffer image dent from Toyota recall*. Retrieved from: http://www.autonews.com/article/20100308/GERMAN_NEWSLETTER/303079988/asian-rivals-suffer-image-dent-from-toyota-recall

Azimian, A., Kilgour, D. M., & Noori, H. (2016). Mitigating contagion risk by investing in the safety of rivals. European Journal of Operational Research, 254(3), 935-945.

Bekaert, G. Harvey, C. R., & Ng, A. (2005). Market integration and contagion. *Journal of Business, 78*(1), 39-70.

Bromiley, P., & Marcus, A. (1989). The deterrent to dubious corporate behavior: Profitability, probability and safety recalls. *Strategic Management Journal, 10*(3), 233-250.

Brown, D. A. (2007). Pensions and risk aversion: The influence of race, ethnicity, and class on investor behavior. *Lewis and Clark Law Review, 11*(2), 385-406.

Brun, W. (1994). Risk perception: Main issues, approached and findings. In G. Wright and P. Ayton (Eds.), *Subjective probability* (395-420). Chichester: John Wiley and Sons.

Business Wire. (2013). *AIG launches service to estimate cost of product recalls; Raises contaminated product insurance limits to $35 million.* Retrieved from: http://www.businesswire.com/news/home/20131015006146 /en/AIG-Launches-Service-Estimate-Cost-Product-Recalls

Byrne, J. (2013). International energy policy in the aftermath of the Fukushima Nuclear Disaster, *Center for energy and Environmental Policy*, 2013.

Christopher, M., & Peck, H. (2004). Building the resilient supply chain. *The International Journal of Logistics Management, 15*(2), 1-14.

Claessens, S., & Forbes, K. (2001). International financial contagion: An overview of the issues and the book. In *International Financial Contagion* (3-17). Springer, Boston, MA US.

Coombs, W. T., & Holladay, S. J. (2001). An extended examination of the crisis situations: A fusion of the relational management and symbolic approaches. *Journal of Public Relations Research*, *13*(4), 321-340.

Coombs, W. T., & Holladay, S. J. (2002). Helping crisis managers protect reputational assets initial tests of the situational crisis communication theory. *Management Communication Quarterly, 16*(2), 165-186.

Corsetti, G. Pericoli, M., & Sbracia, M. (2005). Some contagion, some interdependence': More pitfalls in tests of financial contagion. *Journal of International Money and Finance, 24*(8), 1177-1199.

Covello, V. T., von Winterfeldt, D., & Slovic, P. (1987). Communicating scientific information about health and environmental risks: Problems and opportunities from a social and behavioral perspective. In C. J. Davies, V. T. Covello, and F. W. Allen (Eds.), Risk communication., Washington, D.C.: Conservative Foundation.

Crafton, S. M., Hoffer, G. E., & Reilly, R. J. (1981). Testing the impact of recalls on the demand for automobiles. *Economic Inquiry, 19*, 694-703.

Cvetkovich, G. (2013). *Social trust and the management of risk*. Routledge.

Dahlhamer, J. M., & D’Souza, M. J. (1997). Determinants of business disaster preparedness in two U.S. metropolitan areas. *International Journal of Mass Emergencies and Disasters,15*, 265-281.
Dowdell, T. D., Govindaraj, S., & Jain, P. C. (1992). The Tylenol incident, ensuing regulation, and stock prices. *Journal of Financial and Quantitative Analysis, 27*(2), 283-301.
Drabek, T. E. (1991). Anticipating organizational evacuations: Disaster planning by managers of tourist-oriented private firms. *International Journal of Mass Emergencies and Disasters, 9*(2), 219-245.
Drabek, T.E. (1995). Disaster responses within the tourist industry. *International Journal of Mass Emergencies and Disasters*, *13*(1), 7-23.
DW.com. (2016). Japan closes last nuclear plant currently on the grid. Retrieved from http://www.dw.com/en/japan-closes-last-nuclear-plant-currently-on-the-grid/a-17089432
EMDAT database. (n.d.). Accessed from http://www.emdat.be/database
Emerson, R. M. (1962). Power-dependence relations. *American Sociological Review, 26,* 31-41.
Enerknol Research. (2015). New offshore oil regulations respond to key failures of deepwater horizon spill. *Breaking Energy*. Retrieved from http://breakingenergy.com/2015/04/27/new-offshore-oil-regulations-respond-to-key-failures-of-deepwater-horizon-spill/
Ewing, J. (2015). Volkswagen says 11 million cars worldwide are affected in diesel deception. *Nytimes.com.* Retrieved from https://www.nytimes.com/2015/09/23/business/international/volkswagen-diesel-car-scandal.html
Forbes, K., & Rigobon, R. (2002). No contagion, only interdependence: Measuring stock market comovements. *The Journal of Finance, 57*(5), 2223-2261.
French, J. R., Raven, B., & Cartwright, D. (1959). The bases of social power. *Classics of Organization Theory*, 311-320.
Greenhouse, S. (2014). Some retailers rethink their role in Bangladesh. *Nytimes.com.* Retrieved from http://www.nytimes.com/2013/05/02/business/some-retailers-rethink-their-role-in-bangladesh.html?_r=0
Gupta, A., & Lad, L. J. (1983). Industry self-regulation: An economic, organizational and political analysis. *Academy of Management Review, 8,* 416-425.
Heal, G., & Kunreuther, H. (2007). Modeling interdependent risks. *Risk Analysis, 27*(3), 621-634.
Henrion, M. & Fischhoff, B. (1986). Assessing uncertainty in physical constants. *American Journal of Physics, 54,* 791-798.
Intel, C. (2015). Impact of coal and nuclear outages. *Blogs.constellation.com.* Retrieved from: http://blogs.constellation.com/energy4business/2011/04/01/impact-of-coal-nuclear-outages
Ito, H., & Lee, D. (2005). Assessing the impact of the September 11 terrorist attacks on US airline demand. *Journal of Economics and Business, 57*(1), 75-95.
Japanbullet.com. (2011). Over 80% of Japan's reactors offline. Retrieved from: http://www.japanbullet.com/news/over-80-of-japans-reactors-offline

Jarrell, G., & Peltzman, S. (1985). The impact of product recalls on the wealth of sellers. *The Journal of Political Economy, 93*(3), 512-536.

Jensen, C. (2015). A record year of recalls: Nearly 64 million vehicles. *Nytimes.com.* Retrieved from http://www.nytimes.com/2015/02/13/business/auto-safety-recalls-set-record-of-nearly-64-million-vehicles-in-2014.html?_r=0

Johnson, S. (2015). The politics of meat. *FRONTLINE, PBS*. Retrieved from: http://www.pbs.org/wgbh/pages/frontline/shows/meat/politics/

Jordans, F. (2015, September 21). EPA: Volkswagen thwarted pollution regulations for 7 years. Retrieved from: http://detroit.cbslocal.com/2015/09/21/epa-volkswagon-thwarted-pollution-regulations-for-7-years/

Kahneman, D., & Tversky, A. (1972). Subjective probability: A judgment of representativeness. *Cognitive Psychology, 3*(3), 430-454.

Kahneman, D., Slovic, P., & Tversky, A. (1982). Judgment and uncertainty: Heuristic and biases. New York, NY: Cambridge University Press.

Kaminsky, G. L.; Reinhart, C. M., & Vegh, C. (2003). The unholy trinity of financial contagion. *Journal of Economic Perspectives, 17*(4), 51-74.

Kasperson, R. E., Renn, O., Slovic, P., Brown, H. S., Emel, J., Goble, R., Kasperson, J. X., & Ratick, S. (1988). The social amplification of risk: A conceptual framework. *Risk Analysis, 8*(2), 177-187.

Kasperson, R.E., Jhaveri, H., & Kasperson, J.X. (2005). Stigma and the social amplification of risk: Ttowards a framework of analysis. In: J. X. Kasperson, & R. E. Kasperson (Eds.), *The Social Contours of Risk* (161-180). London: Earthscan.

Keh, H. T., & Xie, Y. (2009). Corporate reputation and customer behavioral intentions: The roles of trust, identification and commitment. *Industrial Marketing Management, 38*(7), 732-742.

Kelly, M., & Gráda, C. Ó. (2000). Market contagion: Evidence from the panics of 1854 and 1857. *American Economic Review, 90*(5), 1110-1124.

Kollewe, J. (2010). BP disaster raises oil industry's insurance costs. *The Guardian.* Retrieved from https://www.theguardian.com/business/2010/jun/03/oil-rig-insurance-costs-soar

Kunreuther, H., & Michel-Kerjan, E. (2004). Dealing with extreme events: New challenges for terrorism risk coverage in the US. *Center for Risk Management and Decision Processes*, Wharton School, University of Pennsylvania.

Miller, K. (1991). A framework for integrated risk management in international business. *Journal of International Business Studies, 23*(2), 311-331.

Minister for Agriculture and Water Resources. (2016). Latest Media Releases. Retrieved from http://minister.agriculture.gov.au/ joyce/Pages/default.aspx

Palmeri, C., & Rupp, L, (2013, May 3). Disney Bangladesh exit pressure on clothesmakers who stay. Retrieved from: http://www.bloomberg.com/news/articles/2013-05-03/disney-bangladesh-exit-puts-pressure-on-those-who-may-stay-1-

Parliament of Canada. (2013). Proceedings of the standing senate committee on agriculture and forestry. Retrieved from http://www.parl.gc.ca /content /sen /committee /411%5CAGFO /31EV-50033-E.HTM

Pidgeon, N., Hood, C., Jones, D., Turner, B., & Gibson, R. (1992). Risk perception. In G. Royal Society Study (Ed.), *Risk: Analysis, Perception, and Management* (89-134). London: The Royal Society.

Pidgeon, N., Kasperson, R. E., & Slovic, P. (2002). The social amplification of risk. Cambridge, UK: Cambridge University Press.
Reilly, R.J., & Hoffer, G. E. (1983). Will retarding the information flow on automobile recalls affect consumer demand? *Economic Inquiry, 21,* 444-447.
Ropeik, D. (2009). Risk communication and non-linearity. *Human and Experimental Toxicology, 28*(1), 7-14.
Rowe, G., & Wright, G. (2001). Differences in expert and lay judgments of risk: Myth or reality? *Risk Analysis, 21*(2), 341-356.
Seo, S., Jang, S. S., Almanza, B., Miao, L., & Behnke, C. (2014). The negative spillover effect of food crises on restaurant firms: Did Jack in the Box really recover from an E. coli scare? *International Journal of Hospitality Management*, *39,* 107-121.
Sharma, L. L., Teret, S. P., & Brownell, K. D. (2010). The food industry and self-regulation: Standards to promote success and to avoid public health failures. *American Journal of Public Health, 100*(2), 240-246.
Sitkin, S. B., & Pablo, A. L. (1992). Reconceptualizing the determinants of risk behavior. *Academy of Management Review, 17*(1), 9-38.
Skjong, R., & Wentworth, B. H. (2001, January). Expert judgment and risk perception. In *The Eleventh International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.
Slovic, P. and Weber, E.U. (2002). Perception of risk posed by extreme events. Paper presented at the Columbia-Wharton/Penn Roundtable on Risk Management Strategies in an Uncertain World, Palisades, New York, 1-21.
Slovic, P. (1987). Perception of risk. Science, *236*(4799), 280-285.
Slovic, P. (1996). Perception of risk from radiation. *Radiation Protection Dosimetry, 68*(3-4), 165-180.
Slovic, P., Fischhoff, B., & Lichtenstein, S. (1982). Why study risk perception. *Risk Analysis, 2*(2), 83-93.
Slovic, P., Fischhoff, B., & Lichtenstein, S. (1984). Behavioral decision theory perspectives on risk and safety. *Acta psychologica, 56*(1), 183-203.
Slovic, P., Fischhoff, B., & Lichtenstein, S. (1985). Characterizing perceived risk. *Perilous progress: Managing the hazards of technology*, 91-125.
Slovic, P., Flynn, J., & Layman, M. (1991). Perceived risk, trust, and the politics of nuclear waste. *Science, 254,* 1603–1607.
Slovic, P. (1997). Trust, emotion, sex, politics, and science: Surveying the risk-assessment battlefield. In: M. Bazerman, D. Messick, A. Tenbrunsel, & K. Wade-Benzoni (Eds.), Psychological Perspectives to Environmental and Ethical Issues in Management (277–313). San Francisco, CA: Jossey-Bass.
Souza, K. (2013). Apparel is a renewed focus at Wal-Mart (updated). Retrieved from http://www.thecitywire.com/node/30164#.VjbXuberS00
Starr, C. (1985). Risk management, assessment, and acceptability. *Risk Analysis, 5,* 97-102.
Statista. (2015). The Walt Disney Company - revenue by operating segment 2014. *Statistic.* Retrieved from http://www.statista.com/statistics/193140/revenue-of-the-walt-disney-company-by-operating-segment/
Statistics Canada. (2009). Mad cow disease and beef trade: An update. Retrieved from http://www.statcan.gc.ca/pub/11-621-m/11-621-m2004010-eng.htm

Stolte, J. F., & Emerson R. M. (1976). Structural inequality: Position and power in network structures. In R. Hamblin and J. Kunkel (Eds.), *Behavior Theory in Sociology* (131-149). New York, NY: Trans-Action.
Sturgeon, J. (2014). The rise of vehicle recalls in Canada in one chart. *Global News*. Retrieved from http://globalnews.ca/news/1246183/chart-the-rise-and-fall-of-vehicle-recalls-in-canada/
Sunstein, C. R. (2003). Beyond the precautionary principle. *University of Pennsylvania Law Review, 151,* 1003-1058.
Taylor, A. L., Dessai, S., & de Bruin, W. B. (2014). Public perception of climate risk and adaptation in the UK: A review of the literature. *Climate Risk Management, 4,* 1-16.
Tversky, A., & Kahneman, D. (1982). Evidential impact of base rates. In D. Kahneman, P. Slovic, & A. Tversky. *Judgment Under Uncertainty: Heuristics and Biases.* (153-163). Cambridge University Press.
Tversky, A., & Kahneman, D. (1985). The framing of decisions and the psychology of choice. In *Environmental impact assessment, technology assessment, and risk analysis*. (107-129). Berlin, Heidelberg: Springer.
Thirumalai, S., & Sinha, K. K. (2011). Product recalls in the medical device industry: An empirical exploration of the sources and financial consequences. *Management Science, 57*(2), 376-392.
Thomsen, M.R., & McKenzie, A. M. (2001). Market incentives for safe foods: An examination of shareholder losses from meat and poultry recalls. *American Journal of Agricultural Economics, 83*(3), 526-637.
Trefis Team. (2015, September 25). The domino effect of Volkswagen's emissions scandal. Retrieved from http://www.trefis.com/stock/vlkay/articles/315035/the-domino-effect-of-volkswagens-emissions-scandal/2015-09-25
USDA ERS - Statistics and Information. (2016). Ers.usda.gov. Retrieved from http://www.ers.usda.gov/topics/animal-products/cattle-beef/statistics-information.aspx
Uzzi, B. (1996). The sources and consequences of embeddedness for the economic performance of organizations: The network effect. *American Sociological Review, 61,* 674–698.
Uzzi, B. (1999). Embeddedness in the making of financial capital: How social relations and networks benefit firms seeking financing. *American Sociological Review, 64*, 481-505.
VBN. (2015). Vietnam bans peanut imports from India after finding 'dangerous' insect pest. Retrieved from https://www.vietnambreakingnews.com/2015/02/vietnam-bans-peanut-imports-from-india-after-finding-dangerous-insect-pest/
Wachinger G., Renn O., Begg C., & Kuhlicke C. (2013). The risk perception paradox—Implications for governance and communication of natural hazards. *Risk Analysis, 33*(6), 1049-1065.
Wachinger, G., & Renn, O. (2010). Risk perception and natural hazards. *CapHaz-Net WP3 Report, DIALOGIK non-profit Institute for Communication and Cooperative Research.* Retrieved from http://caphaz-net.org/outcomesresults/CapHaz-Net_WP3_Risk-Perception.pdf
Wagner, S. M., & Bode, C. (2006). An empirical investigation into supply chain vulnerability. *Journal of Purchasing and Supply Management*, *12*(6), 301–312.
Weber, C. S. (2013). Cultural differences in risk tolerance (IWE Working Paper No. 01-2013). Erlangen: Institut für Wirtschaftswissenschaft.

Weber, E. U. (2004). Perception matters: Psychophysics for economists. *The Psychology of Economic Decisions, 2,* 163-176.

Weber, M. (1947). The theory of social and economic organization, translated by A. M. Henderson and T. Parsons. T. Parsons (Ed.). New York, NY: Free Press.

Welle, D. (2015). Germanwings plane crash hits stocks. Retrieved from http://www.dw.com/en/germanwings-plane-crash-hits-stocks/a-18336537

Chapter 3. Empirical Evidence on Contagion

Abstract

This study is an early work attempting to measure the impact of contagion by using product recalls in two very different industries (meat and toy). The study examines small to moderate events as opposed to extreme events, such as an explosion in a nuclear power plant, where contagion is clearly evident and documented. The focus on testing using samples from small to moderate recall events seems to have been lost somehow. The study explores the conditions under which a non-extreme event can trigger contagion. I find that "signal value" - the non-severity factor of an event, injury counts, recall size, and the size of the recalling firm can contribute to the level of contagion.

Keywords: Contagion Risk, Event Study, Product Recall, Signal Value

3.1. Introduction

Most of the documented cases of contagion in the world were triggered by extreme events; however, there are cases where the triggering events were not actually severe. For instance, when one of the Three Mile Island reactors partially melted on March 28, 1979, its small radioactive releases had no detectable health effects on the plant workers or the public. However, the accident turned the public against nuclear power, causing the nuclear industry to grind to a halt. Another example is the mad cow disease in 2003 in Canada where a single contaminated cow that never entered the food stream cost the live cattle and beef industry approximately $7B.

These observations pose the question of whether non-extreme events can also initiate contagion. This is an important research question because the result will indicate how frequent contagion is, and whether contagion risk should be included in the supply chain risk management strategy of every firm. To answer this question, I consider product safety recalls in the meat and toy industries. In my study, I hypothesize and test the relationships between the sectoral contagion[8] effect and the key attributes of the industry, recalling firm, and recall.

A product recall is a request to return a product after the discovery of safety issues or product defects that might endanger customers or put the maker/seller at risk of legal action. The rate of product recalls continues to expand mostly because of more powerful testing methods and tighter regulations (Anon, 2016). Several significant recalls occurred during the 2016 calendar year, affecting the marketplace across all product categories from dairy and poultry to clothing and automotive parts. The reason for choosing a product recall is two-fold. First, product recalls are not generally catastrophic; second, they are quite common when measured on the industry basis, although they rarely happen to a single firm.

To measure the contagion effect, I use the "event study" methodology to capture the abnormal returns[9] of the firms producing products similar to the recalled product around the recall announcement date. Some studies in the marketing and economics literature have

---

[8] Sectoral contagion is a type of contagion that affects a specific sector of the economy limited to a particular industry (e.g., the Three Mile Island nuclear accident in 1979), geographical region (e.g., Toyota's acceleration pedal problem in 2009), or market (e.g., the U.S. mad cow crisis in 2003) as opposed to "global contagion" which influences an entire economy.

[9] Abnormal return is the difference between the actual change in stock price and a benchmark to adjust for the overall industry and market-wide influences.

examined the "secondary effect".[10] However, the issue with these studies is that their results are mixed and sometimes contradicting. For instance, Hoffer et al. (1988) show that contagion is not statistically significant in the automotive industry. Dranove & Olsen (1984) find that the recalls of five dangerous drugs negatively affected competitors, while Ahmed et al. (2002) conclude that direct competitors see significant gains following drug withdrawals. Similarly, Govindaraj et al. (2004) find that competitors experienced a significant gain in market value following a recall by Bridgestone Corporation. Unfortunately, none of these studies discuss the factors that might have contributed to their findings. This is an important limitation, as testing the impact of an event without controlling for the covariates generally leads to erroneous statistical significance and false inference. For example, firms offering diverse substitute products could remain unaffected following a product recall made by a rival, while those selling only products similar to the recalled product may be affected significantly. Ignoring the impact of product diversity can create either type I or type II errors, depending on the sample structure. To address this limitation, I test the contagion effect of recall announcements in this study while controlling for several factors including event type, event size, and the type and size of the recalling firm. The study proceeds as follows: Section 2 discusses the hypotheses examined. Section 3 describes the collection of the sample data. The basics of the event study methodology are described in Section 4. Section 5 presents and interprets the result of the event studies and analyzes how the shareholder value loss associated with recalls is moderated by various factors. Section 6 discusses the implications of my results on dealing with recalls. The final section summarizes the paper.

[10] The contagion effect can also be called the "secondary effect" as opposed to the "primary effect" which refers to the impact of a recall on the recalling firm.

3.2. Issues and hypotheses examined

Based on the results of the second chapter, I hypothesize the impact of the key attributes of recall, recalling firm, and industry on the magnitude of the secondary effect (contagion effect).

A product safety recall can stimulate customers' concerns about the safety of similar products in the market and drive them to stop buying related products, not only from the recalling firm, but also from other firms in the same market or industry. This behavior can be explained by the "availability heuristic" (Tversky & Kahneman, 1973). People often use heuristics to reduce complex problem solving to more simple judgmental operations. These rules work well under most circumstances, but they can lead to systematic deviations from logic, probability, or rational choice theory (Gigerenzer, 1991). The "availability heuristic" is a type of heuristic that relies on immediate examples that come to mind when evaluating risks. It operates on the notion that events that can be more easily brought to mind or imagined are judged to be more likely than events that could not easily be imagined. This cognitive bias generally increases for negative events, as people apply more weight to negative instances than positive ones when making a judgment. In a survey conducted in 2012 on the performance of S&P 500 Index in 2009, 2010, and 2011, a majority of respondents felt as though the market was either flat or down in 2009, and roughly half said the same about 2010 and 2011 (Franklin Templeton Investments, 2012). In reality, the S&P 500 saw double digit gains in 2009 and 2010, and a modest gain in 2011. This is consistent with other results, in that more painful, negative events that can be recalled (e.g., the 2009 economic crisis) often have a larger influence than positive events when making judgments (Davis, 2017). When a product safety recall occurs, the recall triggers recollections of past recalls, especially the worst ones, because they are easier to remember, or in other words, more available. This phenomenon is evidenced by Seo et al. (2014). For example, in early 1993, more than 700 people became sick and four children died because of the E. coli outbreak in Jack in the Box restaurants, which proved to be one of the most significant food poisoning outbreaks in U.S. history. Seo and his co-authors found that Jack in the Box's stock prices exhibited significantly negative responses to other firms' food crises that occurred from 1994 to 2010, especially when the crisis was closer in time and similar in nature.

Based on the above discussion, I posit that a product recall will negatively influence customers' purchasing decisions for similar products. This reaction shifts the demand curve until customers' trust is regained. The more severe the initiating recall event, the larger the shift will be. A loss of sales and the cost of regaining customers' trust can drive investors to value affected firms in an industry at a discount compared to similar firms in other industries. The fear of tighter regulation and increases in operating costs across the industry as a result of the recall can intensify negative reactions of investors. My first hypothesis is:

H1a. A product recall negatively affects the market value of all firms selling products similar to the recalled product (the secondary effect).

H1b. The secondary effect is larger when the primary effect is more negative.

Hypotheses H1 is about the overall stock market reaction to product recall announcements. However, it is also of interest to identify factors that could influence the direction and magnitude of the market reaction. The factors influencing the contagion effect can be classified into three groups: 1) factors related to the initiating event of recall, 2) factors related to the recalling firm, and 3) factors related to the industry.

An important event related factor is severity. Two dimensions of severity are "injury count" and "recall size". When there is a large product recall, more publicity is needed to inform all customers. Publicity not only alerts those who have already bought the product, but also potential buyers of similar products. As discussed, bad news distorts the risk perceived by individuals because of the "availability heuristic". This means that more publicity will discourage more potential buyers from buying. On the other hand, larger product recalls indicate that more customers are at risk, especially when the injury count is high; therefore, it is more likely that the government will react by enforcing more stringent regulations. Thus, my hypotheses on event severity are:

H2a. The secondary effect will be more negative when the recall size is larger.

H2b. The secondary effect will be more negative when the injury count is higher.

The other event-related factor is the "signal value", the factor that causes the perceived severity of an event to be different from its actual severity. My third hypothesis is that the stock market's reaction to the industry will be more negative when the "signal value" of the event is higher. Early theories link social risk judgments and responses to "event severity" measured by the number of casualties or amount of damage. However, events such as the Three Mile Island nuclear accident in 1979 and the mad cow crises in Canada and the U.S. in 2003 had no fatalities but had huge social impact and demonstrate that a property other than the event’s "severity" contributes to the public’s perception of the event’s seriousness. This property is referred to as the "signal value".

The signal value of an event, and thus its potential social impact, appears to be systematically related to the risk profile of the event. An accident that takes many lives may produce relatively little social disturbance (beyond that caused to the victims’ families and friends) if it occurs as part of a familiar and well-understood system (e.g., a train wreck). However, a small incident in an unfamiliar system (or one perceived as poorly understood), such as a nuclear waste repository or a recombinant DNA laboratory, may have immense social consequences if it is perceived as a harbinger of future and possibly catastrophic mishaps. (Slovic and Weber, 2002)

To predict the signal value of an event, Slovic et al. (1985) developed a "Dread Risk – Unknown Risk" factor space. The "Dread Risk" factor refers to perceived lack of control, catastrophic potential, fatal consequences, and the inequitable distribution of risks and benefits. The "Unknown Risk" factor is the extent to which a hazard is unobservable, unknown, new, and delayed in its manifestation of harm. Slovic (1987) demonstrated that potential signal value is closely related to the position of an event within the factor space. The higher an event’s score is on the Dread factor, the higher its perceived risk is (Slovik & Weber, 2002). As for the "Unknown Risk" factor, familiarity with an event (e.g., acquired by daily exposure) lowers perceptions of its risk (Weber, 2006). Given the above discussion, I hypothesize the following:

H3. The secondary effect of a recall will be more negative when the signal value of its initiating event is larger.

The next hypothesis is about the role of similarity in the contagion effect, which is explained by the "representativeness heuristic" or the "similarity heuristic" (Tversky & Kahneman, 1982). The similarity heuristic explains how people make judgments based on the similarity between current situations and other situations or prototypes of those situations. The goal of the similarity heuristic is to maximize productivity through favorable experiences while not repeating unfavorable experiences. This explains why people tend to shape their world view by their past experiences and incorporate them into their current experiences. As mentioned before, heuristics can lead to systematic deviations from logic, probability, or rational choice theory. The resulting errors are referred to as "cognitive biases" and many different types have been documented. The cognitive biases resulting from a similarity heuristic include ignoring prior probabilities, assuming that similarity in one aspect leads to similarity in other aspects, and assuming that a small sample is representative of a much larger population. A typical situation that includes these biases is when consumers overestimate the extent to which a firm, superficially similar to a recalling rival, is prone to the same event that hit the rival, even though the firm is drawn from a population containing relatively safe firms.

The similarity of a firm to its rival can lie in its product, process, technology, sector, market, industry, supply chain, or origin. For instance, a survey conducted on Toyota's accelerator pedal problems in 2009 showed that the public connected other Asian automakers, including Honda, Hyundai, and Nissan, with the problems. In explanation of this finding, an expert argued that in customers' minds, Toyota was rated as the highest in quality among Asian carmakers, leading them to conclude that other manufacturers with the same origin (Asia) would have even more problems with quality (Automotive News, 2010). As another example, in their studies on automobile recalls, Crafton et al. (1981) and Reilly & Hoffer (1983) show that industry rivals that produce similar lines of cars suffer sales declines following serious automobile recalls.

Multidimensionality of similarity implies that firms are perceived more similar when they look similar on more dimensions (i.e., product, industry, origin, etc.). For example, two meat packing firms are perceived more similar as opposed to a meat packer and a retailer selling meat products. Hence, a recall made by a meat packing company is more likely to negatively affect other meat packing companies, as opposed to one made by a retailer. With respect to my reasoning, I hypothesize:

H4. The secondary effect will be more negative when the recalling rival and the affected firm are from the same sector of the industry.

3.3. Sample selection procedure and data description

The recall samples used in this study are collected from the meat and toy industries. These two industries are selected because the literature shows that the primary impacts of recalls for both industries are statistically significant (Chu et al., 2005; Thomsen and McKenzie, 2001)[11]. The recall announcements were gathered from the recall case archive of the U.S. Food Safety and Inspection Service (FSIS) and the U.S. Consumer Product Safety Commission (CPSC) recall databases. The data was collected for the period of 1982 to 2014. All data about the firms, including return, debt, book value, SIC code, closing price,

[11] According to the literature, the primary impact in the meat industry is significant only for class-I recalls. Class-I recalls are for dangerous or defective products that predictably could cause serious health problems or death.

number of shares outstanding, and market return needed for evaluation of the abnormal returns of recalling firms and industry portfolios was collected from Wharton Research Data Services, CRSP and Compustat databases.

As reported in Table 3-1, totals of 129 meat (beef, pork and poultry) class I recalls and 162 toy recalls made by public companies or their subsidiaries were identified. A three-day window was used for the primary event study, and recalls made by the same firm within two days after another one were excluded.[12] This correction caused the number of the recalls to decrease to 124 meat and 156 toy recall announcements. One meat and one toy recalls were excluded from the analysis because of missing return data near the event. In addition, six meat recalls and eight toy recalls were excluded because the related financial ratios needed for primary regression analysis was missing from the Center for Research in Security Prices (CRSP). Similarly, for the secondary event study, I excluded recalls made by the same firm within two days after the first recall, leaving 117 meat and 146 toy recall announcements. Seven meat and six toy recalls announcements were excluded from the secondary regression analyses because of missing financial information.

To make sure that the recall dates provided by FSIS and CPSC were the earliest dates, I used Factiva, a business information and research tool owned by Dow Jones & Company, to compare the recall dates with the dates news announcements were reported by newswires or newspapers. For meat recalls, seven announcements were not found on Factiva, and seven additional announcements were reported up to three days earlier than FSIS announcement dates.

[12] When a dummy variable was used and the points were kept, the results remained substantially unchanged.

Table 3-1: Description of Recall Announcements

Panel A: Sample Size and Breakdown of Firms' Types

	Meat	Toy
Initial Sample Size	129	162
Primary Event Study Sample Size	124	156
Primary Regression Analysis Sample Size	117	148
Secondary Event Study Sample Size	117	146
Secondary Regression Analysis Sample Size	110	140
Breakdown of the firms' types	53 meat processor 34 food packers 23 retailers	72 toy manufacturer & toy retailers 35 retailers 33 others
Breakdown of the events' types	51 pathogenic 59 other reasons	15 lead contamination 125 other reasons

Panel B: Descriptive Statistics

		Sale (000)	Market Value (000,000)	Market to Book	Debt to Equity
Meat	Max	99,137	70,557	47.74	0.97
	Min	284	26	0.19	0.17
	Average	11,435	5,082	3.68	0.44
	Median	13,661	10,257	2.75	0.43
Toy	Max	74,259	42,424	15.02	0.93
	Min	22	10	0.41	0.05
	Average	3,833	3,129	3.17	0.33
	Median	4,259	4,621	2.99	0.29

For the toy industry, only one recall was not found on Factiva and three announcements were reported up to one day earlier. FSIS and CPSC announcements were used when the announcement date was earlier than news on Factiva, or when the news was not found on Factiva. From 110 meat recalls left for the secondary regression analysis, 53 recalls were made by meat processors, 34 recalls were made by food processors, and 23 recalls were announced by retailers. Fifty-one announcements were made due to contamination with a pathogen, such as E. coli, listeria, hepatitis, or salmonella, and the rest were made because of foreign object contamination, undeclared allergens, or other reasons. From 140 toy recalls, 72 were announced by toy manufacturers or toy retailers, 35 by retailers, and 33 by others, such as McDonald's. Only 15 recalls were announced because of excessive levels of lead, and the rest were initiated because of laceration, choking, chemical, burning hazards, or other reasons.

3.4. Methodology

3.4.1. Event Study

To estimate the shareholder value loss associated with recall announcements of rivals, I used the event study methodology (see Kothari and Warner, 2006). The methodology uses abnormal returns to provide an estimate of the percent change in stock price associated with an event. In an efficient market, the impact of an event is immediately reflected in stock prices, and hence a measure of the impact can be obtained by observing stock price behavior over relatively short time periods. The key features of the event study methodology and how to estimate the abnormal returns are briefly explained here.

Different models have been developed to estimate abnormal returns. The model I used is the market model on daily stock price returns, as this is the best specified model and controls for the systematic risk of the stock, a key factor in explaining stock returns. The model suggests a linear relation between the return on a stock and the market return over a given time period as:

$$r_{it} = \alpha_i + \beta_i r_{mt} + \varepsilon_{it} \qquad (1)$$

where r_{it} is the return of stock *i* on Day *t*, r_{mt} is the market return on Day *t*, α_i is the intercept of the relationship for stock *i*, β_i is the slope of the relationship for stock *i* with the market return, and ε_{it} is the error term for stock *i* on Day *t*. α_i is an estimate of the constant daily return for stock *i*, $\beta_i r_{mt}$ is the portion of the return for stock *i* that is due to market-wide movements, and the error term, ε_{it} , is the part of the return of stock *i* that cannot be explained by market movements and captures the effect of firm-specific information. For each sample firm, I estimated $\hat{\alpha}_i, \hat{\beta}_i$ and $\hat{S}^2_{\varepsilon_i}$ (the variance of the error term, ε_{it}) using ordinary least square regression (see Eq. (1)) on data over an estimation period of 200 trading days. To ensure proper estimates of alpha and beta, a minimum of 40 return observations in the estimation period was required to keep the announcement in the analysis. A_{it}, the abnormal return for stock *i* on Day *t*, is the difference between r_{it}, the actual return of stock *i* on Day *t*, and $(\hat{\alpha}_i + \hat{\beta}_i r_{mt})$ the normal (or expected) return on stock *i* on Day *t*, and is expressed as:

$$A_{it} = r_{it} - \left(\hat{\alpha}_i + \hat{\beta}_i r_{mt}\right) \quad (2)$$

Averaging the abnormal returns across the sample firms on any Day t, the daily mean abnormal, $\bar{A}_t$, can be expressed as:

$$\bar{A}_t = \sum_{i=1}^{N} \frac{A_{it}}{N} \quad (3)$$

where N is the number of sample observations on Day *t*. The cumulative abnormal return over a given time period ($t_1, \ldots, t_2$) is the sum of the daily mean abnormal returns, $\bar{A}_t$, and is expressed as:

$$CAR(t_1, t_2) = \sum_{t=t_1}^{t=t_2} \bar{A}_t \quad (4)$$

To test the statistical significance of the daily mean abnormal return of Eq. (3), each abnormal return, A_{it}, is first divided by its estimated standard deviation of error, $\hat{S}_{\varepsilon_i}$, to yield a standardized abnormal return, A^S_{it}:

$$A^S_{it} = \frac{A_{it}}{\hat{S}_{\varepsilon_i}} \quad (5)$$

The test statistic, TS_t, for any Day t is given by:

$$TS_t = \sum_{i=1}^{N} \frac{A_{it}^{S}}{\sqrt{N}} \tag{6}$$

The rationale behind Eq. (6) is that under the null hypothesis, abnormal returns are assumed to be independent across firms with mean 0 and variance $\hat{S}_{\varepsilon_i}^2$. From the central limit theorem, the sum of N standardized independent abnormal returns is therefore normal, with mean 0 and variance N, which leads to Eq. (6). The test over multiple days (t_1... t_2) is derived similarly, with the additional assumption that abnormal returns are independent and identically distributed across time. The multiple day test statistics, TS_c, is given by:

$$TS_c = \sum_{i=1}^{N} \frac{\sum_{t=t_1}^{t=t_2} A_{it} \Big/ \sqrt{\sum_{t=t_1}^{t=t_2} \hat{S}_{\varepsilon_i}^2}}{\sqrt{N}} \tag{7}$$

Consistent with most event studies, I used a three-day event period to measure the secondary impact for each of the toy and meat industries. I made an industry portfolio based on the Standard Industry Classification Code (SIC) of the firms. The SIC code is a system for classifying industries by a four-digit code. The SIC codes representing meat and toy industries are listed in Table 3-2. The number and combination of the firms in an industry changes as new firms start or as current firms change, expand their industry or stage in the value chain, are bought, go private, or go out of business. Therefore, the portfolios were updated for every trading day. Only firms that were in the toy or meat industries at a trading day were included in the industry portfolio of that day.

Table 3-2: List of SIC codes representing meat and toy industry

Meat Industry SIC codes
2011: Meat Packing Plants 5147: Meats and Meat Products 2013: Sausages and Other Prepared Meats Products 2016: Poultry Slaughtering and Processing 5144: Poultry and Poultry Products
Toy Industry SIC codes
3942: Dolls and Stuffed Toys 3944: Games, Toys, and Children's Vehicles, except Dolls and Bicycles 5092: Toys and Hobby Goods and Supplies 5945: Hobby, Toy, and Game Shops 3940: Dolls, Toys, Games and Sporting and Athletic

The equally weighted daily returns of the industry portfolio was evaluated for each trading day between January 1, 1984 and December 31, 2014. Using an equally weighted portfolio return prevents single large firms from overwhelming the responses of all others in the industry. The following formula was used to compute the portfolio returns:

$$Ret_{ew_t} = \frac{\sum_{i=1}^{i=N} Ret_{i_t}}{N} \tag{8}$$

where Ret_{ew_t} denotes an equally weighted return of portfolio in day t and Ret_{i_t} refers to the closing price in trading day *t-1* for firm *i*. To make sure that the abnormal return of the portfolio would not be diluted by the abnormal return of the recalling firms, the recalling firms were excluded from the portfolio for the dates in which they made recalls and for the days before and after the recall dates. To prevent market crashes from inflating negative results, I assumed that market returns and portfolio returns were undetermined for the stock market crash dates.

3.4.2. Capturing signal value

As mentioned, the signal value of an event causes the perceived severity of an adverse event to be different from its actual severity. Actual severity can be estimated by the injury count (N_{Cas}) and the amount of damage (N_{Dam}), and perceived severity can be measured by the number of news releases (N_{nws}), which depends on both actual severity and signal value. By orthogonalizing the measure of perceived severity against the measures of actual severity, we have:

$$N_{nws} = k_1 N_{Cas} + k_2 N_{Dam} + Residue \tag{9}$$

or

$$Residue = N_{nws} - k_1 N_{Cas} - k_2 N_{Dam} \tag{10}$$

where k_1 and k_2 are coefficients and $Residue$ represents the part of N_{nws} that cannot be explained by N_{Cas} and N_{Dam}. In my tests, $Residue$ is used to estimate signal value.

3.5. Results

Table 3-3 demonstrates the recalling firm’s daily abnormal return (primary effect) and the industry’s daily abnormal return (secondary effect) for the meat and toy industries. The results show that, on average, the primary and secondary effects of meat and toy recalls are negative; however, the effects are not statistically significant, except for the primary effect of toy recalls (equally weighted t-statistic of -2.1). The event period equally weighted mean abnormal return of a recalling firm is -0.51% for meat recalls and -0.89% for toy recalls. The equally weighted mean abnormal return of the industry during the event period for both meat and toy recalls is -0.05%.

Table 3-3: Event Study Results

Event period description	Primary Effect Test				Secondary Effect Test			
	Meat industry		Toy industry		Meat industry		Toy industry	
Estimation Period	-260 to -11							
Event Period	-1 to 1							
Min. required return obs.	40							
Estimation Model	Market Model							
Observations	124		156		117		146	
	EW	VW	EW	VW	EW	VW	EW	VW
Non-clustered test results								
t- test statistic	-1.7	-1.7	**-2.1[c]**	**-2.7[d]**	-0.4	-0.9	0.3	-0.3
Wilcoxon z-statistic	-0.47	-0.47	**-2.1[c]**	**-2.8[d]**	-0.81	-0.78	-0.27	-0.19
Mean-return	-0.0051	-0.0051	-0.0090	-0.0108	-0.0005	-0.0012	-0.0005	-0.0015
Median-return	-0.0011	-0.0011	-0.0034	-0.0056	-0.0012	-0.0007	0.0006	0.0005
% positive	0.48	0.48	0.42	0.43	0.47	0.46	0.51	0.51
minimum return	-0.30	-0.30	-0.21	-0.21	-0.06	-0.07	-0.08	-0.11
maximum return	0.12	0.12	0.10	0.09	0.14	0.077	0.07	0.09

Significance levels (two-tailed tests): (a) 10% level, (b) 5% level, (c) 1% level, (d) 0.5% level

Table 3-4: Primary Effect Regression Analysis Results

	Meat-EW	*Meat-VW*	*VIF*	*Toy-EW*	*Toy-VW*	*VIF*
Intercept	**-0.1483[b]**	**-0.1500[b]**		**-0.0911[b]**	**-0.0959[b]**	
Size	**0.0103[d]**	**0.0106[d]**	1.187	**0.0051[b]**	**0.0056[c]**	1.974
Market to Book	-0.0004	-0.0003	1.117	-0.0001	-0.0009	1.781
Debt to Equity	0.0367	0.0365	1.179	0.0302	0.0243	1.718
Injury counts	0.0000	0.0000	1.225	0.0003	0.0002	1.169
Recall Size	**-0.0028[a]**	**-0.0031[b]**	1.266	-0.0004	-0.0006	1.170
Firm's Type	-0.0019	-0.0023	1.386	-0.0017	0.0021	2.029
Signal Value	-0.0001	-0.0001	1.010	-0.0001	-0.0001	1.163

Significance levels (two-tailed tests): (a) 10% level, (b) 5% level, (c) 1% level, (d) 0.5% level

After controlling for the size, growth prospects, capital structure, recall size, firm type and signal value, the equally-weighted average primary abnormal returns for the meat and the toy industries change to -14.8% (significance level of 5%) and -9.1% (significance level of 5%), respectively (see table 3-4). Firm size and recall size are statistically significant for the meat industry, but only the firm size is statistically significant for the toy industry.

Firm size was measured as the natural logarithm of sales in the most recent fiscal year that ended prior to the recall announcement date. Market-to-book, which is the proxy for growth potential, was measured as the ratio of the market value of equity to the book value of equity. Debt to equity, which is the proxy of capital structure, was measured by the ratio of the book value of debt to the sum of the book value of debt and the market value of equity. To compute these ratios, I used the market value of equity 10 trading days before the recall announcement date, the book value, and the market value of the equity reported in the most recent fiscal year ending prior to the announcement date.

To test my hypotheses I used the following model:

$$\textbf{Sec-Abret}_i = \beta_0 + \beta_1 \textbf{ Prim-Abret}_i + \beta_2 \textbf{Recall-Size}_i + \beta_3 \textbf{Injury-Count}_i + \beta_4 \textbf{Signal-Value}_i + \beta_5 \textbf{ Firm-Type}_i + \varepsilon_i$$

where Sec-Abret$_i$ is the event period average abnormal return of firms in the industry. Prim-Abret$_i$ is the event period abnormal return of firm i. The predicted sign of the coefficient β_1 is positive. Recall-Size$_i$ is the natural logarithm of the total amount recalled or recovered. The predicted sign of the coefficient β_2 is negative. Injury-Count$_i$ is the number of recall casualties and deaths. The predicted sign of the coefficient β_3 is negative. Signal-Value$_i$ represents the signal value of the recall items' initiating event.

To measure the signal value of an event, I first regress the number of news releases within seven days after the event date on primary abnormal return, severity, and firm type, and then subtract the regressed number from the observed number of news. The predicted sign of coefficient β_5 is negative. Firm-Type$_i$ is an indicator variable that measures the type of the recalling firm. It has a value of 1 if the recalling firm is a manufacturer in the industry; otherwise, it will be 0. The predicted sign of coefficient β_6 is negative. Table 3-5 summarizes my predictions for the coefficients.

Table 3-5: Predicted Sign of the Coefficients

Variable	*sign*
Intercept	?
Primary CAR	+
Injury count	-
Recall Size	-
Firm Type	-
Signal Value	-

Table 3-6 presents the results for both the meat and toy industry. The results support three of the five hypotheses. As predicted, the estimated coefficient of primary-effect is positive and significant. Therefore, a firm may experience a more negative abnormal return when the abnormal return of the recalling firm is more negative. I predicted a negative coefficient for the injury counts. The estimated coefficient of injury-count is negative and significant, indicating that the negative consequence of recall for the industry is more severe when more casualties are connected to the recall. I also predicted a negative relationship between the signal value and the secondary abnormal return. The signal value coefficient is negative and significant, indicating that negative public impression regarding an event has a direct relationship on the severity of the secondary effect. The firm type and recall size coefficients are negative as I predicted, but they are not statistically significant. Therefore, the results do not support the relationship between firm type and recall size and secondary abnormal return. Overall, the model is significant with an F value of 2.95 (p-value of 1.5%) and an adjusted R^2 of 12%, which are quite strong, given that my regression is based on cross-sectional data.

Table 3-6: Secondary Effect Regression Analysis Results

	Meat-EW	*Meat-VW*	*VIF EW(VW)*	*Toy-EW*	*Toy-VW*	*VIF EW(VW)*
Intercept	0.0032	0.0031		-0.0030	-0.0028	
Primary CAR	**0.1015**[b]	**0.0951**[b]	1.030(1.040)	0.0383	0.0574	1.012(1.017)
Injury counts	**-0.0001**[b]	**-0.0001**[b]	1.164(1.164)	0.0000	0.0000	1.139(1.140)
Recall Size	-0.0005	-0.0005	1.273(1.281)	0.0001	0.0001	1.146(1.147)
Firm's Type	-0.0011	-0.0010	1.311(1.311)	0.0035	0.0035	1.090(1.084)
Signal Value	**-0.0002**[b]	**-0.0002**[b]	1.002(1.003)	0.0001	0.0001	1.016(1.024)

Significance levels (two-tailed tests): (a) 10% level, (b) 5% level, (c) 1% level, (d) 0.5% level

For the toy industry, the regression analysis result does not support any of the six hypotheses. One reason may be that, unlike meat recalls, toy recalls are not classified into different classes, implying that my toy recall sample is diluted with less important announcements. This argument is supported by the smaller controlled primary effect (intercept) of toy recalls relative to meat recalls (Table 3-4). Another possible reason is the commoditization level of the toy industry. Materials, designs, and processes used in the toy industry are more diverse than those in the meat industry, causing consumers to perceive relatively less similarity between products recalled and products made by other firms in the toy industry as opposed to the meat industry. A third reason could be that, as opposed to the meat industry where the supply chain is in-shore or mid-shore, the supply chain of the toy industry is a mix of in-shore, mid-shore, and off-shore. This further adds to the heterogeneity of the industry, causing it to be more difficult to detect the effect.

3.6. **Implication for managers**

My findings clearly indicate that contagion can happen even when events are common; therefore, it is necessary to assess and manage contagion risk. An obvious question for a manager is how contagion risk can be assessed and what strategies can be adopted to avoid or mitigate the risk of contagion.

The findings show that for the meat industry, the risk of contagion depends on the number of casualties, the signal value of the initiating event, the size of the primary effect, the size of the recalling firm, and the recall size. These factors can be classified into two groups: The factors known before the event (lead factors) and those that are known after (lag factors). The number of casualties, recall size and primary effect of the recall are found out after the recall announcement, but the commoditization level of an industry, average size of the firms in the industry and the signal value of the typical recall initiating events are known beforehand. A decision maker can use the leading factors to assess the risk of contagion. For example, a firm that is operating in a highly commoditized industry, such as the meat industry, with many small competitors who are vulnerable to high signal value events such as listeria, salmonella, E. coli and hepatitis, is at a high risk of contagion because of pathogenic contamination.

The fact that larger firms have more resources to invest in safety measures implies that those firms are generally safer than their smaller rivals. Therefore, the managers of larger firms are reasonable to deem that their risks of contagion are higher when their industries are dominated by small firms, especially when their stakeholders are highly sensitive to safety issues, such as product/customer, operations/ employees, or society/environment safety.

Given that similarity is the key driver of contagion, managers in highly commoditized industries should be more alert to contagion. Differentiating and/or publicizing the differences can help managers to mitigate the fear of lay stakeholders. Transparency and visibility of the supply chain enables a firm's stakeholders to identify and recognize the differences between the firm and its rivals; however, managers should be careful about the extent of information they share with stakeholders. Some information may be misinterpreted by stakeholders, causing them to be mislead. In addition, too much information can confuse stakeholders and lead to an unfavourable outcome by masking key information.

3.7. **Summary and Conclusion**

The main objective of this research is to provide empirical evidence on the contagion effect of non-extreme events. To quantify the effect, I measured the average abnormal returns of the industry following the recall announcements in the meat and toy industries. While the result does not support the hypothesis that on average, the entire industry is adversely affected, it evidences that the industry can be seriously impacted under certain circumstances.

According to my findings, the average abnormal return of the industry and the impact of the hypothesized factors on the abnormal return are statistically insignificant for the toy industry. The average abnormal return is insignificant for the meat industry as well, but the impact of primary-abnormal-return, signal-value, injury-count, recall size, and the size of the recalling firm are significant at the level of 0.05.

My findings are important because they give decision makers an idea of the potential risks involved in having unsafe rivals and they can help decision makers assess their contagion risks by evaluating "lead factors". Lead factors are known before an event occurs, such as the commoditization level of the industry, average size of the firms in the industry, and the signal value of the event.

The paper contributes to the literature by shedding light on the conditions under which a non-severe event can cause contagion. The paper also contributes by introducing a new methodology for capturing the signal value, a non-severity attribute of an event which characterizes its perceived risk. Third, the findings can explain why the findings of other research about the contagion effect are mixed.

A natural extension of this research is to test the impact of other potential contributing factors, such as supply chain visibility, length of supply chain, the extent to which the industry is technology intensive, market share of the recalling firm, average size of the firms in the industry, and the size of the industry. Future research can replicate the study for other types of events, such as operational mishaps or social responsibility accidents. Future studies can also test the contagion effect using accounting-based performance measures or study how long, on average, it takes for an industry to recover from contagion and what parameters contribute to recovery time. Finally, another opportunity for future research is to find the optimal number of days after the event for the accurate measurement of its signal value.

3.8. **References**

Ahmed, P., J. Gardella, & Nanda, S. (2002). Wealth effects of drug withdrawals on firms and their competitors. *Financial Management, 31*, 21-41.

Anon. (2017). 2016 Emerging Trends in Product Recall and Contamination Risk Management.Retrieved from http://www.aon.com/attachments/risk-services/product-recall-2016.pdf

Automotive News. (2010). Asian rivals suffer image dent from Toyota recall. Retrieved from http://webcache.googleusercontent.com/search?q=cache:BwftJgiN7 g EJ:www. autonews.com/ article/20100308/german_newsletter/ 303079988/asian-rivals-suffer-image-dent-from-toyota-recall+&cd=1&hl=en&ct=clnk&gl=ca

Azimian, A., Kilgour, M., & Noori, H. (2015). Mitigating contagion risk by investing in the safety of rivals. Working paper.

Chu, T. H., Lin, C. C., & Prather, L. J. (2005). An extension of security price reactions around product recall announcements. *Quarterly Journal of Business and Economics, 44*(3/4), 33-48.

Crafton, S. M., Hoffer, G. E., & Reilly, R. J. (1981). Testing the impact of recalls on the demand for automobiles. *Economic Inquiry, 19*, 694-703.

Davis, A. M. (2017). Biases individual decision making. Forthcoming in The handbook of behavioral operations management. Donohue, K., Katok, E., & Leider, S. New York, NY: John Wiley and Sons Inc.

Dowdell, T. D., Govindaraj, S., & Jain, P. C. (1992). The Tylenol incident, ensuing regulation, and stock prices. *Journal of Financial and Quantitative Analysis, 27,* 283-301.

Dranove, D., & Olsen, C. (1994). The economic side effects of dangerous drug announcements. *Journal of Law and Economics, 37*(2), 323-348.

Franklin Templeton Investments. (2012). Investors should beware the role of 'availability bias'. Retrieved from http://www.businessinsider.com/the-availability-bias-is-driving-investor-decisions-2012-10

Gigerenzer, G. (1991). How to make cognitive illusions disappear: Beyond "heuristics and biases". *European Review of Social Psychology, 2*, 83–115.

Govindaraj, S., Jaggi, B., & Lin, B. (2004). Market overreaction to product recall revisited – The case of Firestone tires and the Ford explorer. *Review of Quantitative Finance and Accounting, 23*(1), 31-54.

Hoffer, G. E., Pruitt, S. W., & Reilly, R. J. (1988). The impact of product recalls on the wealth of sellers: A reexamination. *Journal of Political Economy, 96*, 663-670.

News works. 2013. Horse meat scandal plays out in newspaper ads. Retrieved from http://www.newsworks.org.uk/News-and-Opinion/horsemeat-scandal-plays-out-in-newspaper-ads

Reilly, R. J., & Hoffer, G. E. (1983). Will retarding the information flow on automobile recalls affect consumer demand? *Economic Inquiry, 21*, 444-447.

Seo, S., Jang, S. S., Almanza, B., Miao, L., & Behnke, C. (2014). The negative spillover effect of food crises on restaurant firms: Did Jack in the Box really recover from an E. coli scare? *International Journal of Hospitality Management, 39*, 107-121.

Slovic, P., & Weber, E. U. (2002). Perception of risk posed by extreme events. Paper presented at the Columbia-Wharton/Penn Roundtable on Risk Management Strategies in an Uncertain World, Palisades, NY, 1-21.

Slovic, P. (1987). Perception of risk. *Science*, *236*(4799), 280-285.

Slovic, P., Fischhoff, B., & Lichtenstein, S. (1985). Characterizing perceived risk. *Perilous Progress: Managing the Hazards of Technology*, 91-125.

Thompson, M. R., & McKenzie, A. M. (2001). Market incentives for safe foods: An examination of shareholder losses from meat and poultry recalls. *American Journal of Agricultural Economics, 83*(3), 526–538.

Tversky, A., & Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. *Cognitive psychology*, *5*(2), 207-232.

Tversky, A., & Kahneman, D. (1982). Evidential Impact of Base Rates. In D. Kahneman, P. Slovic, A. Tversky (Eds.), *Judgment nder uncertainty: Heuristics and biases* (153-163). Cambridge University Press.

USDA ERS - Statistics & Information. (2016). Ers.usda.gov. Retrieved from http://www.ers.usda.gov/topics/animal-products/cattle-beef/statistics-information.aspx

Weber, E. U. (2006). Experience-based and description-based perceptions of long-term risk: Why global warming does not scare us (yet). *Climatic change*, *77*(1), 103-120.

Chapter 4. Management of Contagion Risk

Abstract

Each firm faces not only its own direct risks, but also the contagion risks imposed by rivals who, for example, avoid strong safety measures because investment cost exceeds expected loss. The conclusion of this article is that, in an extreme case, low-risk firms may benefit from investing in safety improvements for their higher-risk rivals. For example, a firm that over-complies with safety requirements may benefit from investing in safety improvements for a rival that complies with regulations at a minimal level. This research explores conditions under which such a contagion risk mitigation strategy is profitable. My findings indicate that, for a low-risk firm, there is a threshold above which such an investment would be profitable. In a market where the price sensitivity to a rival's safety is close to zero, a low-risk firm can decrease this threshold by extending the investment horizon. The investment is less likely to pay off when firms compete on quantity, as opposed to price. I also show that, below a threshold market price, a third firm that is neutral (neither invests nor needs investment) may be put at a cost disadvantage when this contagion risk mitigation strategy is implemented.

Keywords: Analytics, Behavioral OR, Supply Chain Risk Management, Contagion Risk, Safety Investment

4.1. Introduction

Research on Supply Chain Risk Management (SCRM) has mostly addressed threats associated with customers (e.g., Breiter & Huchzermeier, 2015; Gümüs, 2014; Sodhi, 2005; Treville et al., 2014) or suppliers (e.g., Chaturvedi & Martínez-de-Albéniz, 2011; Gurnani et al., 2014; Wang et al., 2010). However, very little Supply Chain (SC) research focuses on risks posed by rivals. In this paper, I address this gap by making use of *contagion risk* and examining whether, and when, investment in rivals' safety measures can mitigate it.

By definition, contagion risk can be classified as an "environmental risk" from the source-of-risk perspective and as an "industry risk" from the scope-of-impact view. Environmental risks are defined as events driven by external forces, such as weather, earthquakes, political, regulatory, and market forces (Wagner and Bode, 2006). Industry risks include those that may not affect all sectors of the economy as a whole, but rather specific industry segments (Miller, 1991). Contagion is also very similar to spillover risk (the probability that a firm is affected because of the failure of a member of its supply chain), but, as discussed in Chapter 2, the process of propagation in contagion is different from spillover.

Contagion risk is well-recognized in many industries, and firms adopt various strategies to manage it. Pharmaceuticals, for example, lobby regulators to tighten restrictions on the import and sale of potentially unsafe drugs which could negatively affect the reputation of the industry. Some industries, such as the nuclear power industry, practice self-regulation to ensure compliance with minimum regulations and help prevent actual regulations from becoming more restrictive and thus costly.

As discussed in Chapter 1, contagion is triggered by an adverse event occurring at a rival or in its SC (Figure 1-2). A triggering event is caused by an *initiating event* which is either *active* (evident) or *dormant* (hidden) and out of the rival's control. For instance, the

Fukushima nuclear meltdown in 2011 was caused by a tsunami, an active incident, whereas the Toyota Sticky Gas Pedal Recall in 2009 was initiated when defective pedals were sent to Toyota to be used on the assembly line, a dormant event. The probability of a triggering event for a single industry may be low, but its frequency across industries is significant.

A triggering event occurs because a rival does not comply with minimum regulations or because compliance with minimum regulations is insufficient to avoid the event. In the latter case, one approach to address the issue is to increase the minimum requirements. However, given that triggering events are rare, further restriction may be seen as over-regulation and opposed by government or industry. An alternative approach is to encourage complying firms to over-comply voluntarily. However, if firms perceive over-compliance as unnecessary or threatening to their competitiveness, or if they believe that the investment costs exceed the expected profit from the investment, they will not over-comply. This applies especially to Small and Medium Enterprises (SMEs) that lack the operational scale to absorb an increase in cost or cannot afford the capital investment where the return may be long term. In this context, low-risk firms who over-comply with safety regulations may consider investing in safety improvements for high-risk rivals that choose to comply only with regulations at a minimum level.

A valuable illustration comes from the meat industry, where I show that a firm might voluntarily help a high-risk competitor to purchase kits to test for mad cow disease. Testing every animal over 21 months old significantly reduces the probability that contaminated meat can enter the food chain. In 2003, a small slaughterhouse in the state of Washington issued a recall for about 10,000 pounds of raw beef that was suspected to be contaminated with mad cow disease. Following the recall, 53 countries banned imports of U.S. beef, costing the American beef industry between $3.2B and $4.7B (Coffey et al., 2005). At the time of the event, the U.S. had an active mad cow disease screening program in place. Records from the Department of Agriculture show that 35,000 animals were tested between 2001 and 2003, but none were tested at the slaughterhouse where the mad cow case was detected (UPI, 2015), despite the slaughterhouse specializing in older and/or injured dairy cattle, which are considered to be at a high risk for mad cow disease.

Since many forms of direct contribution to a rival may be considered “collusion” and possibly illegal, an intermediary association is needed to collect and invest contributions. This association can also verify if a candidate rival requires such financial contribution to improve its safety measures and ensure that the rival follows the requirements of the investing firm. Investment in a rival’s safety provides a non-regulatory mechanism for the governance of contagion risk which can be combined with self-regulation. The culture of collaboration embedded in self-regulation promotes such investments, and self-regulatory organizations (SROs) can play the role of intermediary association. SROs are non-governmental organizations formed by the private sector to set standards, monitor compliance, and enforce rules. An example of a SRO is the Children's Food and Beverage Advertising Initiative (CFBAI), which is designed to influence the advertising of foods targeting children under 12, to encourage healthier dietary choices and lifestyles. The CFBAI is a voluntary self-regulation program and involves 18 of the United States' largest food and beverage companies (as of September 2013), covering approximately 80% of the child-directed food advertising market (OECD.org, 2015).

While all firms are at risk of contagion, over-complying firms should be more concerned as they can be penalized for risks that they have already addressed internally.

Furthermore, it may not be a priority for firms that struggle to comply with minimum regulatory requirements since contagion risk is a high-consequence but low-probability risk. My research asks what factors can affect the investment decisions of a low-risk firm and answers how variation in the contributing factors may lead to different decisions. I apply a mathematical approach to explore the conditions under which it would be beneficial for a low-risk firm to improve the product safety measures of a high-risk rival in a market where firms compete on price and demand depends on both price and safety.

This paper contributes to the SC literature by introducing the notion of contagion risk, providing a detailed model of perceived safety, bringing forward a new coopetitive approach to risk mitigation, and addressing the variables contributing to contagion risk. On the practical side, the research underscores the need for low-risk firms to address contagion risk and helps them decide when to consider industry-level safety investments as an effective strategy to manage contagion risk.

In the remainder of the paper, I briefly review the most relevant literature (Section 2), provide a preliminary analysis to set the stage for the problem formulation (Section 3), and propose my analytical model (section 4). Chapter 5 briefly discusses the approaches to contagion management. I conclude by proposing directions for future research.

4.2. Literature Review

4.2.1. Related Streams of Literature

The first relevant area of research focuses on supply risk management in decentralized networks where self-interested interacting firms decide on investment to reduce disruption risk. Most research in this stream (e.g., Baiman et al., 2000; Swinney & Netessine, 2009) explores buyer investment, for example, to enable a supplier to improve its production processes, or to help avoid impending bankruptcy. Researchers have also explored buyer–supplier vertical coordination of investment decisions. For instance, Bakshi & Kleindorfer (2009) consider a bargaining game between a retailer and a supplier facing an interdependent SC disruption risk and discuss how to share investment with SC partners to increase SC resilience.

Another relevant stream of literature combines system reliability theory and probabilistic risk analysis with game theory in the context of protecting a critical infrastructure from risks, such as terrorist attacks. For example, Kim and Tomlin (2013) and Kunreuther & Heal (2005) explore the effects of security investment decisions of one agent on the incentives of other agents. Kunreuther & Heal propose a model of interdependent security where agents are vulnerable to an externality from other agents. They show that when a single successful attack can be catastrophic, the failure of one agent to invest in security can make it unprofitable for other agents to invest. Building on this work, Zhuang & Bier propose a new model that assumes attacks occur over time according to a Poisson process. They find that differences in discount rates among agents can lead some agents with low discount rates not to invest in security and conclude that heterogeneous time preferences can complicate the task of achieving security. Their study shows that the existence of myopic agents can make it undesirable for non-myopic agents to invest in security, and hence they explore subsidizing strategies for such investments.

Information security research focuses on security investments and provides economic models for both security investment and information sharing between firms. For instance, Gal-Or & Ghose (2005) study firms' incentives to share security information and show that information sharing and security investment complement each other. Gordon & Loeb (2002) developed an economic model to determine optimum security investments for protecting an information set with a specific vulnerability and a given potential loss.

Finally, game theory has been applied to decide the quality choice of agents, where demand is assumed to be dependent on both product quality and price. Related research in this stream studies competition either under a vertical relationship (e.g., Gurnani et al., 2006), or horizontal rivalry relationship (e.g., Banker et al., 1998; Xie et al., 2011).

Our research is similar to these four streams of research in that it applies economic modeling to anticipate the optimal level of investment under the assumption that the benefits from a firm's investment depend on other firms' decisions. My work is different from the first stream in that it addresses risks imposed by rivals, whereas most of the research in this stream addresses supply and demand risks. Differences in the relationships of firms affect the nature of constraints and incentives, and hence the modeling of the problem. In the other three streams, firms are horizontally interdependent because of either a common source of risk or a shared market. In my analysis, firms are interdependent because they have both a common source of risk and a shared market, causing the optimal investment level to be constrained by investment cost as well as lost demand. However, the most important factor that differentiates my research from the literature is my distinction between objective safety and perceived safety. The common assumption that demand is a function of actual safety implies that behavioural factors can be neglected. I provide a detailed model of perceived safety and its relationship to objective safety and link these quantities to safety investment.

4.2.2. Perceived Safety and Objective Safety

Safety is categorized as subjective (perceived) or objective (actual). Subjective safety is related to psychological aspects (Stoessel, 2001) while objective safety is based on more quantifiable measures (Suddle & Waarts, 2003). Recognizing this difference is essential in my research because investment improves actual safety while demand is driven by perceived safety. Studies on the relationship between perceived and objective safety are rare in the operations management literature; however, there is considerable research on the relationship between perceived and objective quality. Given that safety is an essential component of a product's quality, it is reasonable to conclude that the features and characteristics of such a relationship in the context of quality can be extrapolated to product safety.

Perceived quality drives preferences and subsequently sales, and it is the general subjective assessment of quality relative to one's own and others' experiences of quality. Objective quality refers to the collective performance of all product attributes (Mitra & Golder, 2006). Some researchers argue that in the long term, changes in objective quality can noticeably influence customer perceptions of quality (e.g., Bolton & Drew, 1991). For instance, Easton & Jarrell (1998) and Hendricks & Singhal (2001) show that actual quality initiatives take between five to 10 years to translate into higher profits. Mitra & Golder (2006) find that in the consumer product industry, it takes on average over six years for a change in objective quality to be fully reflected in customer perceptions of quality. They argue that this delay is caused by uncertainty, lack of knowledge about objective quality, high cognitive efforts required to adjust prior expectations, low involvement, and long inter-purchase frequencies. Some studies have found a significant effect of one-periodlagged quality on the market share of certain products (e.g., Kopalle & Lehmann, 2001; Mitra & Golder, 2006). Mitra & Golder show that in the first year after a quality change, on average 20% of the total effect over time is realized. The academic literature is inconsistent regarding the concurrent effects of changes in objective quality on perceived quality; some studies have found a realized impact from 3% to 22% (e.g., Boulding et al., 1999; Prabhu & Tellis, 2000; Kamakura et al., 2002), whereas others doubt the significance of such an effect (e.g., Bettman et al., 1991).

Building on the above, I conclude that a change in a product's objective safety brought about by investment in safety measures affects perceived safety. However, the full impact is only realized in the long run. All else being equal, it takes more time to reach a higher percentage of the long-term effect (see Section 3.2 for a discussion of how I include this in my model).

4.3. **Preliminary Analyses**

To model the investment problem in Section 4, I first need to define the equilibrium profit of the low-risk firm, $\boldsymbol{\pi_L^*}$, as well as the probability density of contagion, $\boldsymbol{f_{t_{\mathcal{T}}}(t)}$. In Subsection 3.1, I study a duopoly market and model the relationship between equilibrium profit and perceived safety. Using the results of Subsection 3.2, Subsection 3.3 quantifies perceived safety as a function of time and investment level. In Subsection 3.2, the relationship between objective safety and investment level is found and the probability density of contagion risk is formulated.

4.3.1. Duopoly market structure

We consider a duopoly in which two profit maximizing firms, labeled high-risk (H) and low-risk (L) with perceived safety level of s_H and s_L, choose a price level of $p_H$and p_L, where perceived safety is a measurable attribute of product with values in the interval [0, 1]. Building on Banker et al. (1998), I assume that the demand functions for two firms are linear in price and safety as follows:

$$q_i = Q_i - \alpha p_i + \beta p_j + \gamma s_i - \lambda s_j \tag{1}$$

where $Q_i, \alpha, \beta, \gamma, \lambda > 0\ and\ p_i, p_j, s_i, s_j\ \geq 0\ for\ i, j \equiv L, H, i \neq j\ and\ s_L >\ s_H.$ Here, Q_i is the intrinsic demand potential parameter for firm i. I assume any shift in demand caused by safety changes (in s_i and s_j) is captured through the γs_i and λs_j terms; in particular, Q_i does not depend on safety. The α and γ parameters denote the demand responsiveness to the firm's own price and product safety, and β and λ denote the demand responsiveness to the rival's price and product safety, respectively. I also assume that demand for each firm is affected more by its own price and safety than those of its rivals, that is, $\alpha > \beta$ and $\gamma > \lambda$. This is a plausible assumption; otherwise, for example, firms will not lose sales if they both raise their prices by one dollar or decrease their safety levels by one unit. From (1), the profit, revenue minus expenses, is:

$$\pi_i = q_i(\ p_i - c_i) - F_i = \left(Q_i - \alpha p_i + \beta p_j + \gamma s_i - \lambda s_j\right)(\ p_i - c_i) - F_i \tag{2}$$

Maximizing $\pi_i$with respect to p_i produces:

$$p_i^* = \frac{Q_i + \beta p_j^* + \gamma s_i - \lambda s_j + \alpha c_i}{2\alpha} \tag{3}$$

Substituting rival's price, $p_j^* = \frac{Q_j + \beta p_i^* + \gamma s_j - \lambda s_i + \alpha c_j}{2\alpha}$, into (3) produces:

$$p_i^* = A s_i + B s_j + C_i \tag{4}$$

where

$$A = \frac{(2\alpha\gamma - \beta\lambda)}{(4\alpha^2 - \beta^2)} \tag{5}$$

$$B = \frac{(\beta\gamma - 2\alpha\lambda)}{(4\alpha^2 - \beta^2)} \tag{6}$$

$$C_i = \frac{2\alpha Q_i + \beta Q_j + \alpha(2\alpha c_i + \beta c_j)}{(4\alpha^2 - \beta^2)} \tag{7}$$

for $I = H$ and $j = L$, and for $i = L$ and $j = H$. To find the demand associated with the optimal price, I substitute (4) in (1) and find:

$$q_i^* = \frac{Q_i + \beta p_j^* + \gamma s_i - \lambda s_j - \alpha c_i}{2} = \alpha(p_i^* - c_i) \tag{8}$$

We can also formulate the equilibrium profit π_i^* in terms of optimal price p_i^* by substituting (4) and (8) into (2) to find:

$$\pi_i^* = (p_i^* - c_i)q_i^* - F_i = \alpha(p_i^* - c_i)^2 - F_i \tag{9}$$

Since $\alpha > \beta$ and $\gamma > \lambda$, I conclude from (5) and (7) that C_i and A are always positive. However, according to (6), B may take either positive or negative values. When B is positive, I can observe from (4) and (9) that increasing the safety level of the high-risk firm will increase the profit of the low-risk firm. Banker et al. (1998) argues that $B < 0$ is implausible. Accepting this argument for now, I assume that $B < 0$. From (6), I know that B is negative if, and only if $\frac{\alpha}{\beta} > \frac{2\gamma}{\lambda}$, that is, when the relative responsiveness of demand to price $\frac{\alpha}{\beta}$ is greater than twice the relative responsiveness of demand to safety $\frac{\gamma}{\lambda}$.

4.3.2. Modeling contagion risk

As described earlier, contagion is generated by a triggering event, which in turn is caused by an initiating event (Figure 1-2). For example, the 2003 global ban on Canadian beef was triggered by a single case of mad cow disease detected on a farm in Alberta, suspected to have been caused by contaminated cattle feed shipped from a livestock feed mill.

Contagion starts immediately after a triggering event, but the occurrence of an initiating event does not always result in a triggering event. To be precise:

$$Pr\{\mathcal{C}|\mathcal{T}\} = 1 \quad (10)$$

$$0 < Pr\{\mathcal{T}|\mathcal{I}\} \leq 1 \quad (11)$$

where $\mathcal{C}, \mathcal{T}$ and $\mathcal{I}$ denote contagion, triggering event, and initiating event, respectively.

Given that initiating events are rare and their occurrences are independent, I can consider the occurrence of initiating events in the investment horizon as a Poisson process. This implies that the probability that the first initiating event happens before time t has an exponential distribution:

$$\Pr\{t_{\mathcal{I}} < t\} = 1 - e^{-\mu t} \quad (12)$$

Here, $t_{\mathcal{I}}$ denotes the time of the initiating event and μ^{-1} represents the mean time to the first event. Since initiating events are scarce and independent, I can assume that the probability of two or more events within the investment horizon is negligible. The probability of a triggering event before time *t* is then:

$$\Pr\{t_{\mathcal{T}} < t\} = Pr\{\mathcal{T}|\mathcal{I}\} \Pr\{t_{\mathcal{I}} < t\} \quad (13)$$

where $t_{\mathcal{T}}$ denotes the waiting time to the triggering event.

The conditional probability $\Pr\{\mathcal{T}|\mathcal{I}\}$ in (13) represents the probability that a firm's safety measures cannot detect a dormant initiating event or cannot tolerate the consequences of an active initiating event. Given that initiating events are unavoidable, the only option to address contagion is to reduce the probability of the triggering event. One option is to invest in the safety of the firm that is at risk from the initiating event.

To estimate the effect of investment level on $\Pr\{\mathcal{T}|\mathcal{I}\}$, I apply the logistic regression model used by Major (2002) and Bakshi et al. (2009) for estimation of disruption probability:

$$ln\left(\frac{\Pr\{\mathcal{T}|\mathcal{I}\}}{1-Pr\{\mathcal{T}|\mathcal{I}\}}\right) = I - \omega y \tag{14}$$

Here, $y \geq 0$ represents the safety investment level and parameters I and $\omega > 0$ in (14) denote an intercept and coefficient, respectively. Assuming $\Pr\{\mathcal{T}|\mathcal{I}\} \ll 1$ (where "≪" means "much less than"), and setting $\wp_{t0} = e^{-I}$ by, I can approximate $\Pr\{\mathcal{T}|\mathcal{I}\}$ as:

$$\Pr\{\mathcal{T}|\mathcal{I}\} \cong \wp_{t0} e^{-\omega y} \tag{15}$$

In fact, $\wp_{t0}$ denotes the conditional probability of the triggering event before investment. Substituting (12) and (15) into (13) shows that the probability of triggering event is:

$$\Pr\{t_{\mathcal{T}} < t\} = \wp_{\mathrm{t0}} \mathrm{e}^{-\omega \mathrm{y}}(1 - \mathrm{e}^{-\mu \mathrm{t}}) \, . \tag{16}$$

Taking (10) into account, I have:

$$\Pr\{t_{\mathcal{C}} < t\} = \Pr\{t_{\mathcal{T}} < t\} \tag{17}$$

where $t_{\mathcal{C}}$ is the starting time of contagion. Given (17), (16) shows the probability of contagion at or before time t. If I differentiate with respect to t, I find that the probability that the first contagion event occurs in a small interval of time of length dt starting at time t is:

$$f_{t_{\mathcal{T}}}(t)dt = \wp_{t0} e^{-\omega y} \mu e^{-\mu t} dt. \tag{18}$$

Note that (18) represents an approximation to the values of a probability density function at small values of $\boldsymbol{t}$, under the assumptions made above. Below, I will use (18) in integrals representing the loss in profits caused by a triggering event within an investment horizon.

4.3.3. Impact of investment on perceived safety

Investment in a high-risk rival increases the objective safety of its product either by improving the rival's capability to detect dormant initiating events or by increasing the resilience of its operations against active initiating events. Since demand shift is caused by changes in perceived, rather than objective, safety, I need to incorporate the relationship between objective safety and perceived safety into my model. As discussed in Section 2.2, objective safety affects perceived safety, but this effect is realized over time. All else being equal, it takes more time to reach a higher percentage of the long-term effect. The impact of the investment on perceived safety can be best approximated by an exponential function. I assume that perceived safety captures the changes in the objective safety at the rate of $(1 - e^{-\varphi t})$, where φ is the adjustment rate and t is elapsed time since investment. Then:

$$s_H(y,t) = s_{H0} + \theta \, \Delta s_{H\,obj}(y)(1 - e^{-\varphi t}) \tag{19}$$

where s_{H0} and $s_H(y,t)$ denote the perceived safety level of the high-risk firm before and after investment, respectively, $\Delta s_{H\,obj}(y)$ refers to the change in the objective safety after investment, and θ represents the percentage of the changes in objective safety captured by perceived safety. $\Delta s_{H\,obj}(y)$ is defined as:

$$\Delta s_{H\,obj}(y) = \left(s_{H\,obj}(y) - s_0\right) \tag{20}$$

where s_0 and $s_{H\,obj}(y)$ denote the objective safety levels of the high-risk firm before and after investment, respectively.

Given that safety is complementary with risk level, I can assess objective safety from a firm's risk. Using (15), I get:

$$s_{Hobj}(y) = 1 - \Pr\{\mathcal{T}|\mathcal{I}\} = 1 - \wp_{t0} e^{-\omega y} \tag{21}$$

$$s_0 = 1 - \wp_{t0} \tag{22}$$

Substituting (21) and (22) into (20), I find:

$$\Delta s_{H\,max}(y) = \theta \wp_{t0}(1 - e^{-\omega y}) \tag{23}$$

Using (23), I can reformulate (19) as:

$$s_H(y,t) = s_{H0} + \theta \wp_{t0}(1 - e^{-\omega y})(1 - e^{-\varphi t}) \tag{24}$$

We can now substitute $s_H(y,t)$ into (4) and define the low-risk firm's optimal price, p_L^*, and subsequently equilibrium profit, π_L^*, as functions of time and investment level y.

4.4. Modeling

4.4.1. Expected profit of a low-risk firm in the presence of contagion

We consider a market consisting of an over-complying (low-risk) and a minimum-complying (high-risk) firm competing on price, where the low-risk firm is at risk of contagion posed by the high-risk rival. Before the investment (t < 0), the levels of perceived safety and price for the high-risk firm are s_{H0} and p_{H0}, and for the low-risk firm are s_{L0} and p_{L0}, respectively. At time t = 0, the low-risk firm makes an investment decision regarding the high-risk firm's safety level; from that time, the two firms continue to compete on price as perceived safety of the high-risk firm approaches the maximum achievable level (see (19)). From the perspective of the low-risk firm, the optimal safety level of the high-risk firm is the level that maximizes the expected profit of the low-firm's investment for time horizon T.

We assume that for the low-risk firm, the marginal profit of investing in its own safety is less than the marginal profit of investing in the safety of the high-risk firm. This is a reasonable assumption because marginal return diminishes as investment increases, and by definition, the low-risk firm has already made much more internal safety investment than the high-risk firm. I also assume that information is symmetric, and therefore the low-risk firm knows how safe the high-risk firm is and how responsive it is to safety investment.

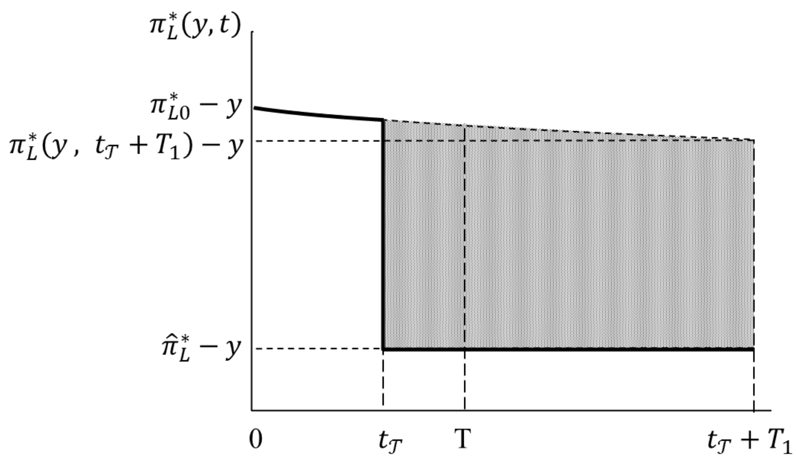

Figure 4-1: Effect of triggering event on the expected profit of a low-risk firm

As depicted above (Figure 4-1), contagion causes the profit of the low-risk firm to drop from $\pi_L^*(y,\ t_{\mathcal{T}}) - y$ to $\hat{\pi}_L^* - y$ at time $t_{\mathcal{T}}$ and last for a period of T_1, where $t_{\mathcal{T}}$ is a random variable and denotes the waiting time to the triggering event. $\pi_{L_0}^*$ represents the profit of the low-risk firm before investment, $\hat{\pi}_L^*$ is the average post-event profit of the low-risk firm, and y is the investment level that low-risk firm makes in the high-risk firm's safety for the investment horizon T. Depending on the nature of the triggering event, $t_{\mathcal{T}} + T_1$ may be smaller or greater than T.

We now assume that the low-risk firm's lost profit after the event is much greater than the maximum reduction in the low-risk firm's profit due to the increase in the high-risk firm's safety level following the investment. That is:

$$\pi_{L0}^* - \hat{\pi}_L^* \gg \pi_{L0}^* - \pi_L^*(y, t_{\mathcal{T}} + T_1) \quad (25)$$

which is equivalent to $p_{Lm} - c_L \gg \sqrt{\frac{\hat{\pi}_L^* + F_L}{\alpha}}$, where p_{Lm} is the low-risk firm's price at $(t_{\mathcal{T}} + T_1)$, c_L is the variable cost, F_L is fixed cost, α is responsiveness of demand to the low-risk firm's own price, and $\gg$ means "is much greater than". Actually, this is a necessary assumption; otherwise, there would be no incentive for the low-risk firm to consider such investment as an option. Assuming (25), I get:

$$(\pi_L^*(y,t) - \hat{\pi}_L^*) \cong (\pi_{L0}^* - \hat{\pi}_L^*) \tag{26}$$

We can now model the present value of the expected profit of the low-risk firm as:

$$E(\pi_L(y)) \cong \int_0^T \pi_L^*(y,t)e^{-rt}\,dt - \int_0^T (T-t)e^{-rt} f_{t_{\mathcal{T}}}(t)\, V_{t_{\mathcal{T}}}(\pi_{L0}^* - \hat{\pi}_L^*)\,dt - y \tag{27}$$

where $V_{t_{\mathcal{T}}}(\pi_{L0}^* - \hat{\pi}_L^*)$ represents the discounted value of expected loss at time $t_{\mathcal{T}} < T$.

$$V_{t_{\mathcal{T}}}(\pi_{L0}^* - \hat{\pi}_L^*) = \int_0^{T_1} e^{-rt}\left(\pi_{L0}^* - \hat{\pi}_L^*\right)dt \tag{28}$$

In (27), $f_{t_{\mathcal{T}}}(t)$ is the probability density of contagion which is defined in (18). From (4) and (9), I know that $\pi_L^*(y,t) = \alpha(p_L^*(y,t) - c_L)^2 - F_L$ where $p_L^* = (\mathrm{As_L} + \mathrm{B}\, s_H(y,t) + \mathrm{C_L})$, and $s_H(y,t)$ is defined by (24). Differentiating (27) with respect to y, I get:

$$\frac{\partial}{\partial y}E(\pi_L(y)) = D_1 e^{-2\omega y} + D_2 e^{-\omega y} - 1 \tag{29}$$

where
$$D_1 = -2\omega\alpha T(B\theta \wp_{t0})^2\left(\left(\frac{1-e^{-rT}}{rT}\right) - 2\left(\frac{1-e^{-(\varphi+r)T}}{(\varphi+r)T}\right) + \left(\frac{1-e^{-(2\varphi+r)T}}{(2\varphi+r)T}\right)\right) \tag{30}$$

$$D_2 = \omega T\left(2\alpha(B\theta \wp_{t0})^2\left(\left(\frac{1-e^{-rT}}{rT}\right) - 2\left(\frac{1-e^{-(\varphi+r)T}}{(\varphi+r)T}\right) + \left(\frac{1-e^{-(2\varphi+r)T}}{(2\varphi+r)T}\right)\right) + 2\alpha(p_{L0} - c_L)B\theta \wp_{t0}\left(\left(\frac{1-e^{-rT}}{rT}\right) - \left(\frac{1-e^{-(\varphi+r)T}}{(\varphi+r)T}\right)\right) + \frac{(\pi_{L0}^* - \hat{\pi}_L^*)(1-e^{-rT_1})}{r}\wp_{t0}\mu\left(\frac{1-\exp^{-(\mu+r)T}}{(\mu+r)T}\right)\right) \tag{31}$$

Coefficient D_1 is always negative because for $f(rT) = \frac{1-e^{-rT}}{rT}$ and $rT > 0$, I know that $f'(rT) = \frac{e^{-rT}(e^{rT} - \mathrm{rT} - 1)}{-(rT)^2} \le 0$ and $f"(rT) = \frac{e^{-rT}(2e^{rT} - (rT)^2 - 2\mathrm{rT} - 2)}{(rT)^3} \ge 0$. This implies that $f(rT) - f(rT + \varphi T) > f(rT + \varphi T) - f(rT + 2\varphi T)$, which is equivalent to

$\left(\frac{1-e^{-rT}}{rT}\right) - 2\left(\frac{1-e^{-(\varphi+r)T}}{(\varphi+r)T}\right) + \left(\frac{1-e^{-(2\varphi+r)T}}{(2\varphi+r)T}\right) > 0$, where $\varphi T > 0$. The zeroes of (29) are $\frac{-1}{\omega} ln \frac{D_2 \pm \sqrt{\Delta}}{-2D_1}$, where $\Delta = D_2{}^2 + 4D_1$. I can demonstrate that (29) has a global maximum at $y^* = \frac{-1}{\omega} ln \frac{D_2 - \sqrt{\Delta}}{-2D_1}$ if and only if:

$$D_1 + D_2 - 1 > 0 \tag{32}$$

The expression $D_1 + D_2 - 1$ is the derivative of the expected profit at y=0.

Substituting the values of D_1 and D_2 from (30) and (31) into (32) generates:

$$\frac{(1-u_L)(1-e^{-rT_1})}{r} \wp_{t0} \mu\omega\alpha \left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)(p_{L0} - c_L)^2 + \tag{33}$$

$$2\alpha\omega B\theta \wp_{t0} \left(\left(\frac{1-e^{-rT}}{r}\right) - \left(\frac{1-e^{-(\varphi+r)T}}{(\varphi+r)}\right)\right)(p_{L0} - c_L) -$$

$$\frac{(1-u_L)(1-e^{-rT_1})}{r} \wp_{t0} \mu\omega F_L \left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right) - 1 > 0$$

where $u_L = \frac{\hat{\pi}_L^*}{\pi_{L0}^*}$. The left side of the above expression is a simple quadratic in $(p_{L0} - c_L)$, which has two roots. Since the leading term has a positive coefficient, (33) holds if, and only if, $(p_{L0} - c_L)$ is less than the smaller root or greater than the larger root. The two roots are $p_{L0} - c_L = z \pm \sqrt{z^2 + \frac{F_L}{\alpha} + \left(\frac{1}{\frac{(1-u_L)(1-e^{-rT_1})}{r} \wp_{t0} \mu\omega\alpha \left(\frac{1-e^{-(\mu+r)T}}{\mu+r}\right)}\right)}$, where z is as defined in (35).

The root corresponding to the negative sign is the smaller root, and must be negative. However, $(p_{L0} - c_L) < 0$ is not possible. Therefore, (33) can be true only if $(p_{L0} - c_L)$ exceeds the larger root, leading us to propose:

Proposition 1: For a low-risk firm, there is a threshold price p_{thL} above which investment in the safety measures of a high-risk rival will be always profitable.

Where (34)

$$p_{thL} \equiv z + \sqrt{z^2 + \frac{F_L}{\alpha} + \left(\frac{1}{\frac{(1-u_L)(1-e^{-rT_1})}{r}\wp_{t0}\mu\omega\alpha\left(\frac{1-e^{-(\mu+r)T}}{\mu+r}\right)}\right)} + c_L$$

and (35)

$$z = \frac{-B\theta\left(\left(\frac{1-e^{-rT}}{r}\right)-\left(\frac{1-e^{-(\varphi+r)T}}{(\varphi+r)}\right)\right)}{\frac{(1-u_L)(1-e^{-rT_1})}{r}\mu\left(\frac{1-e^{-(\mu+r)T}}{\mu+r}\right)}$$

It is obvious that the expression under square root is always positive, indicating that p_{thL} always exists. According to Proposition 1, the optimal investment level $y^* = \frac{-1}{\omega} ln \frac{D_2-\Delta}{-2D_1}$ is strictly positive if, and only if, p_{L0} is greater than p_{thL}. From (24), we can see that in the long run, y^* will increase the perceived safety of the high-risk firm from s_{H0} to $s_{H0} + \theta\wp_{t0}\left(1 - ln\frac{D_2-\Delta}{-2D_1}\right)$.

The sensitivity of threshold price, p_{thL}, to the contributing factors is further investigated (see Appendix 2 for proofs of comparative statistics). I use a numerical example to support the analyses where needed. The factors contributing to threshold price are classified into low-risk firm related factors including r, T, and $\hat{\pi}_L^*$, market related factors including α, θ, B, T_1 and φ, and high-risk firm related factors including ω and $\wp_{t0}$, and the environment-related factor μ.

According to the sensitivity analysis, threshold price is an increasing function of ω (high-risk firm's objective safety responsiveness to investment), but optimal investment is concave in ω (Figure 4-2). The reason for this behavior is that the solution of the investment problem generates an optimal ωy rather than optimal investment level y. Higher ω decreases marginal investment cost, causing optimal ωy to rise. On the other hand, higher ω means less investment is needed to achieve the optimal ωy, driving optimal investment to decline. Such a contradiction causes optimal investment to be concave. All other things constant, ω is expected to be smaller when the size of a high-risk firm is larger, because a larger firm needs more investment to achieve the same safety level as a small firm. Therefore, I expect that firm size and threshold price of the high-risk firm will change in the same direction. On the other hand, smaller firms are more likely to be high-risk because they can be more cost constrained than large firms.

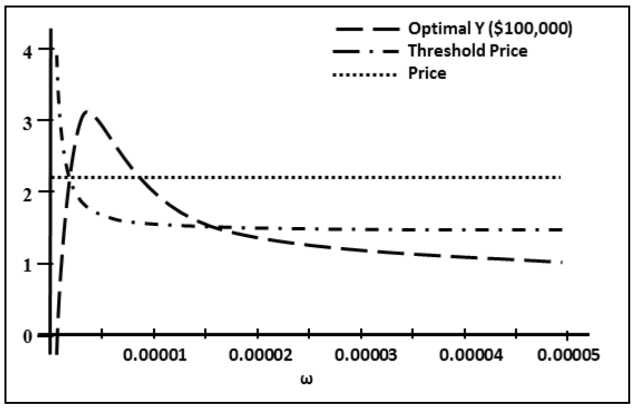

Figure 4-2: Impact of ω, on low-risk firm's threshold price and optimal price

Note: T=10; T_1=5; α=300,051,000; A=0.49; B= - 0.0319; C_L=1.63; F_L=$33,000,000; c_L=$1.0; s_L=0.9; s_{H0}=0.7; μ=0.009; θ=0.50; r=0.05; u_L=0.2; p_{t0}=0.010; p_{L0}= $2.14; φ=0.5

As shown in Figure 4-3, threshold price decreases when the risk of the high-risk firm represented by $\wp_{t0}$ rises and the expected time to initiating event denoted by $1/\mu$, declines. When the risk of the high-risk firm increases from 0.001 to 0.01, the threshold price curve shifts down and crosses the low-risk firm's price faster.

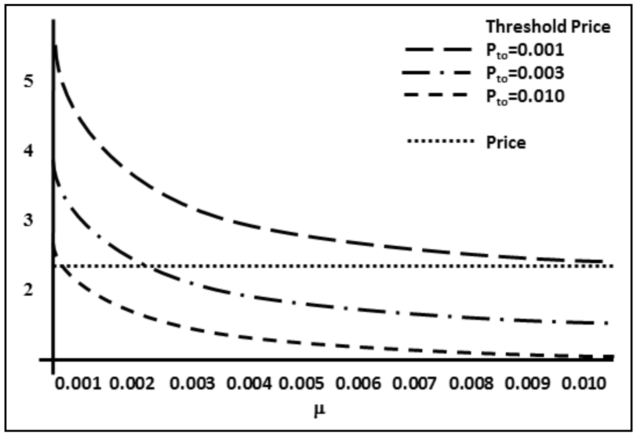

Figure 4-3: Impact of the risk of initiating event on threshold price

Note: T=10; T_1=5; α=300,051,000; A=0.49; B= - 0.0000319; C_L=1.63; F_L=\$33,000,000; c_L=\$1.0; s_L=0.9; s_{H0}=0.7; θ=0.50; r=0.05; u_L=0.2; p_{t0}=0.010; p_{L0}= \$2.14; φ=0.5; ω=0.00001

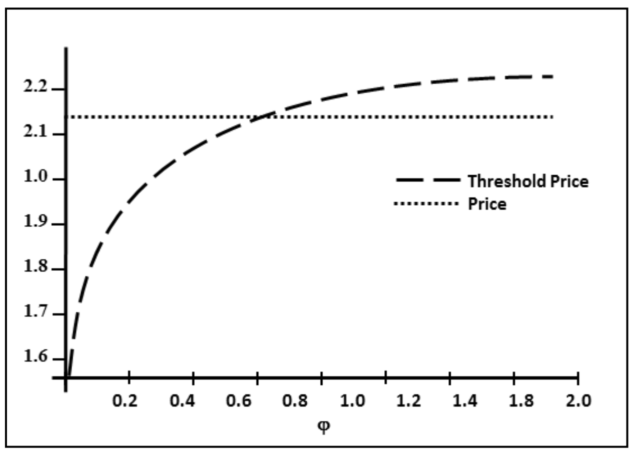

Figure 4-4: Impact of perception adjustment rate (φ) on threshold price

Note: T=10; T_1=5; α=300,051,000; A=0.49; B= - 0.0319; C_L=1.63; F_L=\$33,000,000; c_L=\$1.0; s_L=0.9; s_{H0}=0.7; μ=0.009; θ=0.50; ω=0.00001; r=0.05; u_L=0.2; p_{t0}=0.010; p_{L0}= \$2.14

Regarding market related factors, the direction of the shift in threshold price is the same as for φ (rate of the adjustment of public perception of safety with actual safety), θ (rate of objective safety contribution to perceived safety), and $|B|$ (absolute value of the sensitivity of the optimal price of a firm to the perceived safety of its rival's product), but indefinite for α (demand responsiveness to the firm's own price). The longer it takes for the market to adjust its perception (the larger the φ), the smaller the value of threshold price will be (Figure 4-4.). According to Mitra & Golder (2006), adjustment in perception is relatively faster for product categories with higher quality variance and higher purchase frequency. Therefore, I expect markets dominated with product categories of these types to have relatively larger threshold prices.

Larger $|B|$ raises the threshold price and lessens the price. Larger $|B|$ amplifies the negative effect of the improvement of a rival's safety resulting from investment, and hence has a negative impact on investment profitability. In fact, an ideal market for investment is one with $|B| = 0$. In contrast to $|B|$, the optimal price sensitivity to the firm's own perceived safety denoted by "A" has no impact on the threshold prices; however, "A" has a direct relation with price, and therefore investment in markets with higher "A" values are more likely to be profitable.

Similar to "A", an increase in the optimal price intercept C_L raises the price. C_L is directly related to the potential intrinsic demands of both high-risk and low-risk firms (Q_H and Q_L), which are proxies of the firm's size. Therefore, price has a direct relation to the sizes of both high-risk and low-risk firms. Given that p_{thL} and the high-risk firm's size change in the same direction, total potential intrinsic demand constant ($Q_H + Q_L = cte$), the larger the relative size of the low-risk firm to the high-risk rival, the more likely the investment will be profitable.

Larger T_1 (duration of the impact of adverse event) and smaller $\hat{\pi}_L^*$ (the post-event expected profit) generate smaller threshold prices. Smaller $\hat{\pi}_L^*$ is the result of higher risk perception by the public. Slovic (1987) shows that the public is more anxious when a hazard's scores on "unknown risk" and "dread risk" factors are high and argues that adverse consequence of the events with a high score on these two factors is more likely to spread to other firms. For industries such as the nuclear industry, which experience more hazards of these types, expected post-event profit would be smaller, and hence the investment is more likely to be profitable.

Regarding the low-risk firm's discount rate, r, the sensitivity analysis shows that threshold price and r move in the same direction (Figure 4-5). Higher discount rate decreases the present value of the expected cost, making investment less attractive. Therefore, over-estimation of discount rate may undermine the severity of contagion.

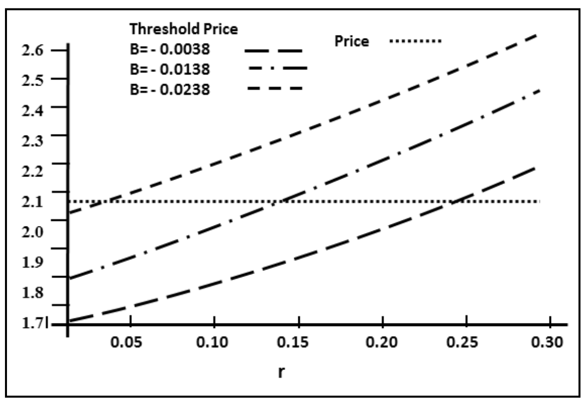

Figure 4-5: Impact of discount rate I on low-risk firm's threshold price

Note: $T=10$; $T_1=5$; $\alpha=300{,}051{,}000$; $A=0.49$; $C_L=1.63$; $F_L=\$33{,}000{,}000$; $c_L=\$1.0$; $s_L=0.9$; $s_{H0}=0.7$; $\mu=0.009$; $\theta=0.50$; $\omega=0.00001$; $r=0.05$; $u_L=0.5$; $p_{t0}=0.010$; $p_{L0}=\$2.14$; $\varphi=0.5$

Variation of investment horizon (T) has an indefinite impact on threshold price, but when $|B|$ approaches zero they move in the opposite direction. This suggests that under certain circumstances, a longer investment horizon can cause an investment to become feasible or more profitable (Figure 4-6). When $|B|$ is relatively large, a longer investment horizon causes the low-risk firm to lose more market share, eroding the profit gained from expected loss reduction and causing T and p_{thL} to move in the same direction. In addition to $|B|$, other factors can also constrain investment horizon. For instance, when a high-risk firm's safety vulnerability derives from its product or technology, the investment horizon cannot exceed the product or technology life cycles. This suggests that investment is more likely to be unfeasible for high-tech industries.

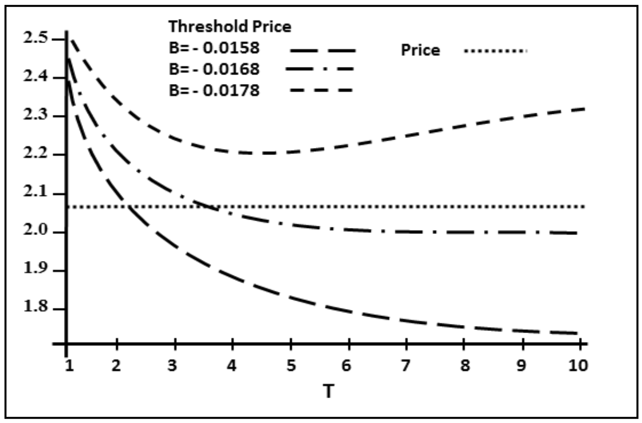

Figure 4-6: Impact of investment horizon T on low-risk firm's threshold price

Note: T_1=5; α=300,051,000; A=0.49; C_L=1.63; F_L=\$33,000,000; c_L=\$1.0; s_L=0.9; s_{H0}=0.7; μ=0.009; θ=0.50; ω=0.00001; r=0.05; u_L=0.5; p_{t0}=0.010; p_{L0}= \$2.14; φ=0.5

Finally, the cost structure of the low risk firm can affect threshold price. A decrease in the variable cost of a low-risk firm, c_L, causes the threshold price to decline and leads to a higher price. Similarly, smaller fixed cost, F_L, results in a smaller threshold price, but has no impact on the price. When fixed cost and variable cost are inversely interdependent (an increase of one causes the other to decrease), the impact of cost structure on investment profitability is indefinite.

4.4.2. Investment profitability under quantity competition

So far, I have assumed that firms compete on price. I can also assume that firms compete on quantity, where prices are determined by the inverse demand functions matching customer demand with the quantities supplied by the competing firms, and their perceived safety levels. That is:

$$p_i = P_i - \alpha q_i - \beta q_j + \gamma s_i - \lambda s_j \; for \;\; i, j = L, H, i \neq j \tag{36}$$

where $\alpha, \beta, \gamma, \lambda, p_i, p_j, s_i$ and s_j are the same parameters I already defined for (1) and P_i is the intrinsic price for firm i. By following the same approach used in section 3.1, I find:

$$p_i^* = \alpha\left(A' s_i + B' s_j + C'_i\right) + c_i \tag{37}$$

where $A' = \frac{(2\alpha\gamma + \beta\lambda)}{(4\alpha^2 - \beta^2)}$, $B' = \frac{(-\beta\gamma - 2\alpha\lambda)}{(4\alpha^2 - \beta^2)}$ and $C'_i = \frac{2\alpha Q_i - \beta Q_j + \alpha\left(2\alpha c_i - \beta c_j\right)}{(4\alpha^2 - \beta^2)}$.

From Section 4.1, I know that an ideal market for investment is one where $B' = 0$; however, contrary to B in (6), B' can hardly obtain a value equal or close to zero. B' asymptotically nears zero when $4\alpha^2 - \beta^2$ goes to infinity or when both $\beta\gamma$ and $\alpha\lambda$ approach zero. $4\alpha^2 - \beta^2$ goes to infinity when price is much more sensitive to a firm's own quantity than its rival's quantity, and $\beta\gamma$ and $\alpha\lambda$ approach zero when at least two of the parameters α, β, γ and λ are close to zero. While plausible, these extreme cases violate the assumption that price depends on the quantity and safety level of both of the companies. In other words, in a market where price is meaningfully dependent on quantity and safety, it is unlikely that B' nears zero. Using the same reasoning used in Section 4.1, I can show that the low-risk firm threshold price and changes of $|B'|$ move in the same direction. Therefore, I propose:

Proposition 2: The investment is less likely to pay off when firms compete on quantity, as opposed to price.

4.4.3. Investment profitability in the presence of a neutral firm

When a market only consists of high-risk and low-risk firms, condition (34) is the only condition for the profitability of the investment. However, a market may also consist of a neutral firm (N) that neither invests nor needs investment. As Appendix 3 explains, I can formulate p_i^*, the optimal price of firm i in this market, as:

$$p_i^* = A''s_i + B''s_{-i} + C''_i \tag{38}$$

where $A'' = \frac{-2\beta\lambda+(2\alpha-\beta)\gamma}{(2\alpha+\beta)(2\alpha-2\beta)}$, $B'' = \frac{\beta\gamma-2\alpha\lambda}{(2\alpha+\beta)(2\alpha-2\beta)}$, $C''_i = \frac{Q_i(2\alpha-\beta)+\beta Q_{-i}}{(2\alpha+\beta)(2\alpha-2\beta)}$ and $s_{-i} = \sum s_j - s_i$ for $i, j = H, L, N, i \neq j$. Under the new market setting, profitability will not be the sole requirement for investment, and the low-risk firm needs to make sure that the investment will not put the neutral firm at a cost disadvantage relative to the high-risk firm; otherwise, the investment may be seen as collusion and deemed illegal. The profitability condition for the neutral firm is similar to that of the low-risk firm in (32), but since the low-risk firm does not invest, its profitability condition is formulated as:

$$\mathrm{D}_{1_N} + \mathrm{D}_{2_N} > 0 \tag{39}$$

Where D_{1_N} and D_{2_N} are the coefficients of the derivative of the neutral firm's profit function similar to D_1 and D_2 in (30) and (31), except that r, B, F_L, p_{L0}, c_L and u_L are replced by r_N, B'', F_N, p_{N0}, c_N and u_N. The solution of equation (39) with respect to $(p_{N0} - c_N)$ leads us to propose:

Proposition 3: For a neutral firm, there is a threshold price p_{thN} above which it will never be negatively affected by the investment of a low-risk firm in the safety measure of a high-risk rival.

where
$$p_{thN} \equiv z_N + \sqrt{{z_N}^2 + \frac{F_N}{\alpha}} + c_N \tag{40}$$

and
$$z_N = \frac{-B''\theta\left(\left(\frac{1-e^{-r_N T}}{r_N}\right)-\left(\frac{1-e^{-(\varphi+r_N)T}}{(\varphi+r_N)}\right)\right)}{\frac{(1-u_N)\left(1-e^{-r_N T_1}\right)}{r_N}\mu\left(\frac{1-\mathrm{e}^{-(\mu+r_N)T}}{\mu+r_N}\right)}$$

Equation (40) suggest that the threshold price of the neutral firm is independent of the attributes of the low-risk and high-risk firms and is sensitive only to the environment risk represented by μ, market attributes including price sensitivity to rivals' perceived safety, denoted by B, and the rate of the adjustment of public perception of safety with actual safety, φ.

4.5. **Discussion**

The supply chain risk management steps for contagion risk are similar to steps for other risks, namely: risk identification, risk measurement, risk assessment, risk evaluation, risk mitigation, and risk monitoring.[13] However, one thing that makes the management of

[13] According to Tummala & Schoenherr (2011), the SCRM process has the following six steps:

1. Risk Identification – involves a comprehensive and structured identification of supply chain risks.
2. Risk Measurement – determination of the consequences of all identified supply chain risks along with magnitudes of their impact.
3. Risk Assessment – assessing likelihood of each risk factor.
4. Risk Evaluation – consists of two sub-steps of risk ranking and risk acceptance.
    a) Risk ranking – involves determining risk exposure value of each risk factor based on consequence severity and probability of occurrence and grouping risks into classes based on risk exposure values.
    b) Risk Acceptance – after supply chain risks are grouped into classes, they are further classified into unacceptable, tolerable, or acceptable risks based on criteria defined by the organization.
5. Risk Mitigation and Contingency Plans – risk mitigation and contingency plans are developed taking into account resource constraints faced by the organization.

contagion different is the identification of the triggering events. As discussed in Chapters 2 and 3, several factors, including the industry, size of the recalling firm, and the signal value of the events contribute to the likelihood and magnitude of contagion. The other difference is the risk mitigation strategy. As the source of contagion is a rival, a (low-risk) focal firm needs to help its (high-risk) rivals improve their safety measures to mitigate contagion risk. I discuss how a firm can identify potential triggering events and the strategies it can adopt to manage contagion risk.

4.5.1. Triggering Event

Firms need to identify events that can trigger contagion to assess and manage the contagion risk associated with a certain event. There are three plausible types of contagion-triggering events. First, black swans: major, unplanned events that have a significant impact. For example, the Deepwater Horizon oil spill in the Gulf of Mexico in 2010 and the Fukushima nuclear reactor disaster in 2011 fall into this category. These are implausible, extreme events with little or no objective basis for a firm to predict, and as such, cannot be identified before they happen.

Second, gray swans: rare, but plausible, events with the potential to destabilize an industry or a market. For example, beef recalls due to mad cow disease and corporate social responsibility events in the apparel industry (e.g., the Rana Plaza building collapse in Bangladesh in 2013) are categorized as gray swan events. These events are so infrequent that a firm or its rivals may never have experienced them, but past occurrences of such

---

6. Risk Monitoring and Control – involves monitoring performance of risk response plans, taking corrective and preventive actions to account for deviations from desired SC performance, abnormal cases or SC disruptions.

events point to their potential. Companies can identify such events by analyzing historical data on negative events that have occurred in the same industry but different markets.

The third type of triggering events falls between the black swans and gray swans.

Similar to black swans, these events are rare, high-profile, difficult to predict, and beyond the realm of normal expectations within the boundaries of the firm's industry; however, similarities between the firm's industry and another industry that has experienced contagion may increase the plausibility that such rare events occur. For example, the recent Volkswagen emission scandal was the first time that a recognized European automaker has violated regulations so blatantly, but it was not the first time a well-known European brand was involved in an operational breach. In 2013, beef burgers sold under Tesco Supermarket's Everyday Value brand were found to contain undeclared horse meat, sometimes up to 100% of the meat content. Investigations later revealed that the complex, Europe-wide supply chains used by Tesco included companies that were fraudulently labelling horse meat.

While Volkswagen and Tesco operate in different industries, both companies produce commodities with volatile prices, are fiercely competitive, and have long, complex supply chains. Given that these shared characteristics increase the risk of opportunism, an operational breach in the automotive industry, such as the 2015 Volkswagen emission scandal, was conceivable after the Tesco horse meat scandal was exposed. Although it is difficult to identify these types of events, firm can expose events that could affect its market or supply chain by finding similarities between industries and looking at historical data on adverse events that have occurred in the same market.

4.5.2. Approaches to contagion risk management

Contagion risk management strategies can be classified into reactive and proactive types. In the reactive approach, a firm attempts to minimize the consequences of an adverse event happening to a rival; in the proactive approach, a firm's objective is to prevent or decrease the probability of the triggering event. As discussed, contagion can affect a firm by interrupting either its supply or demand, or by increasing its operating cost due to tighter regulations. Firms can use strategic public relations to manage the consequences of contagion in order to address the risk of supply or demand disruption. By publicizing information, a firm attempts to convince its stakeholders that it is free of the problems that have recently plagued a rival. When executed effectively, this approach can ease consumers' minds and increase a firm's market share. For example, after Tesco's horse meat scandal in 2013, competitors such as Morrison's, bought multi-page advertisements highlighting their "integrated supply chain" and the reliability of their meat products. Similarly, meat producer associations in the UK, including The National Farmers Union and the British Pork Executive, ran ads encouraging consumers not only to buy quality meat products, but also to buy local or British meat. One tagline read: "Quality Assured. Now more than ever, it's important to know that the meat that you're buying comes from a trusted source". While this approach can be effective, it can also backfire; a poorly planned risk communication strategy can worsen the situation by confusing stakeholders and further spreading fear and negative opinions.

Another effective strategy to manage the risk of increases in operating costs due to tighter safety regulations after an event is lobbying. Lobbying is the act of attempting to influence decisions made by government officials, such as legislators and regulatory agency members. For example, Jack in the Box used lobbying to manage contagion as mentioned in the previous section. However, this in itself can pose a risk of negative publicity if the industry is seen to be resisting changes that could make it safer in the eyes of the general public.

Self-regulating is a strategy to prevent contagion and involves collaborating with other firms to set and enforce rules and standards relating to the conduct of firms in the industry (Gupta and Lad, 1983). Self-regulation complements existing laws by supplementing rules to govern the behavior of firms. Industries choose self-regulation in response to both the lack of government regulation and the threat of excessive government regulation (Sharma et al., 2010). For example, the Forest Stewardship Council was formed in response to industry concerns about the lack of government regulation to address the sustainability of natural resources. Alternatively, self-regulation may be implemented in response to catastrophic events, such as the formation in the U.S. of the Institute of Nuclear Power Operations after the Three Mile Island accident to set power plant safety guidelines.

Investing in the safety of high-risk rivals is a preventative strategy to improve safety and regulatory adherence. Under certain circumstances, investing in the safety of high-risk rivals can be profitable for the investing firm. Investing in a high-risk rival increases the objective safety of its product, either by improving their ability to detect dormant triggers, or by increasing the resilience of its operations against active triggers.

4.6. **Summary and Conclusion**

Herein, I seek to highlight for decision makers the issue of *contagion risk,* or the probability that a firm is adversely affected by the negative externalities of rivals' operational failures. The large number of industry-wide crises caused by operational failures of a single firm indicates that firms are at risk of contagion, a situation that cannot be addressed by internal investment. In this research, I explore whether investment in the safety measures of a high-risk rival is a profitable mitigating strategy. My research indicates that for a low-risk firm, there is a threshold price above which such investment would be profitable, and this price is a function of the attributes of firms, market, and environment. As expected, the threshold price is lower when the consequence of contagion is more drastic or when the probability of a triggering or initiating event is higher. One of the factors that affect the threshold price is the rate that public perception of safety is adjusted to actual safety. My analysis shows that the slower the rate of adjustment, the smaller the threshold price will be. I also find that the threshold price is higher when the low-risk firm's discount rate is larger. The most important factor that affects the investment decision is parameter B, the sensitivity of the optimal price of the low-risk firm to the perceived safety of the high-risk rival. When sensitivity is high, investment could be unprofitable, even if the risk of contagion is significant. When sensitivity is close to zero, the low-risk firm can decrease the threshold price and turn an unprofitable investment into a profitable one by extending the investment horizon. I find that the investment is less likely to pay off when firms compete on quantity, as opposed to price. When a neutral firm is added to the model, investment of the low-risk firm in the high-risk rival may be illegal if it puts the neutral firm at cost disadvantage. There is also a threshold price for the neutral firm above which the firm will not be negatively affected by the investment.

It is worthwhile to comment on whether it is reasonable to expect similar results in a model with spillover effects. The fear generated by an event is amplified as it passes through social links, causing a negative reaction disproportionate to the actual severity of the event. Since fundamental links generally lack such amplification property, it is expected that a small triggering event would not cause a huge effect. In other words, a spillover effect is expected to be significant only if the triggering event is large. On the other hand, it is reasonable to believe that the potential severity of a triggering event has a direct relationship to the size of the firm to which the event happens. This means that a low-risk firm is at risk of spillover only if the high-risk firm is larger than, or comparable in size to, the low-risk firm. However, as indicated in my earlier discussion in Section 4.1, I know that the larger the relative size of high-risk rival to the low-risk firm, the less likely the investment will be profitable. This suggests that when the channel of risk propagation is fundamental, there is less chance that the investment will pay off.

This paper contributes to SCRM literature by introducing the notion of contagion risk, formulating perceived safety, addressing the impacts of firms' and market's attributes on contagion risk, and proposing a new co-opetition approach for mitigating contagion risk. On the practical side, this research underscores the need for low-risk firms to address contagion risk and helps them decide when to consider industry level investment as a contagion mitigating strategy.

In this paper, I focus on a simple duopoly market where firms compete only on price in the absence of moral-hazard and free-rider problems, and under the assumption of information symmetry. Future research can investigate the profitability of the safety investment in a market with multiple high-risk and low-risk firms competing on price and safety, both when firms of a type (low-risk or high-risk) are identical and when they are not. When optimal investment levels of low-risk firms are different, one can explore whether low-risk firms should collaborate and what the optimal level of investment would be for each firm and society. Future research may also explore how to overcome free-rider and moral-hazard problems and incorporate asymmetric information about the type of high-risk firm.

Appendix 4-1

Table A1.1 Notifications definitions

Notation	Explanation	Notation	Explanation
$-H$	High-risk firm	$-t_{\mathcal{I}}$	Time at which initiating event happens
$-L$	Low-risk firm	$-t_{\mathcal{T}}$	Time at which triggering event happens
$-N$	Neutral firm	$-y$	Investment level
$-\alpha$	Demand responsiveness to firm's own price	$-\wp_{t0}$	Probability of triggering event before investment
$-\beta$	Demand responsiveness to rival's price	$-\omega$	High-risk firm's objective safety responsiveness to investment
$-\gamma$	Demand responsiveness to the safety of firm's own product	$-1/\mu$	Average time to first event
$-\lambda$	Demand responsiveness to the safety of rival's product	$-\theta$	Rate of objective safety contribution to perceived safety
$-Q_i$	Intrinsic demand potential parameter of firm *i*	$-f_{t_{\mathcal{T}}}(t)$	Probability density of contagion
$-\pi_i$	Profit of firm *i*	$-s_{H0}/\ s_0$	Perceived/Objective safety of high-risk firm before investment
$-T$	Investment Horizon	$-p_{Lm}$	price of the low-risk firm at $t_{\mathcal{T}} + T_1$
$-T_1$	Duration of the impact of adverse event	$-s_{H\,obj}$	Objective safety of high-risk firm after investment
$-p_i$	Price of firm *i*	$-\Delta s_{H\,obj}$	Change of objective safety of high-risk firm after investment
$-s_i$	Perceived (product) safety level of firm *i*	$-f(\hat{\pi}_L)$	Distribution of the post-event profit of low-risk firm
$-q_i$	Demand of firm *i*	$-\hat{\pi}_L^*$	Average optimal post-event profit of low-risk firm
$-c_i$	Variable cost of firm *i*	$-D_1,D_2$	Coefficients of the derivative of low-risk firm's profit function
$-F_i$	Fixed cost of firm *i*	$-y^*$	Optimal investment level
$-p_i^*$	Optimal price of firm *i*	$-p_{L0}$	Price of the low-risk firm before investment
$-q_i^*$	Demand associated with optimal price of firm *i*	$-r_i$	Discount rate of firm *i*
$-A,A'$	Optimal price sensitivity to firm's own safety(duopoly)	$-A''$	Optimal price sensitivity to firm's own safety (oligopoly)
$-B,B'$	Optimal price sensitivity to rival's safety (duopoly)	$-B''$	Optimal price sensitivity to rival's safety (oligopoly)
$-C_i, C'_i$	Optimal price intercept of firm *i* (duopoly)	$-C_i''$	Optimal price intercept of firm *i* (oligopoly)
$-\mathcal{T}$	Triggering event	$-u_i$	Ratio of post-event profit to pre-event profit of firm *i*
$-\mathcal{I}$	Initiating event	$-\varphi$	Rate of the adjustment of public perception of safety with actual safety
$-\mathcal{C}$	Contagion		

Appendix 4-2

In this appendix, the sensitivity of threshold price p_{th} to contributing variables is analyzed. From (A1.21), I have:

$$p_{th} = z_1 + \sqrt{z_1^2 + \frac{F_L}{\alpha} + z_2} + c_L \tag{A2.1}$$

where

$$z_1 = \frac{-B\theta\left(\left(\frac{1-e^{-rT}}{r}\right) - \left(\frac{1-e^{-(\varphi+r)T}}{(\varphi+r)}\right)\right)}{\frac{(1-u_L)(1-e^{-rT_1})}{r}\mu\left(\frac{1-e^{-(\mu+r)T}}{\mu+r}\right)} \tag{A2.2}$$

$$z_2 = \frac{1}{\frac{(1-u_L)(1-e^{-rT_1})}{r}\wp_{t0}\mu\omega\alpha\left(\frac{1-e^{-(\mu+r)T}}{\mu+r}\right)} \tag{A2.3}$$

Then, for any variable X, I have:

$$\frac{\partial}{\partial X}p_{th} = \left(1 + \frac{z_1}{\sqrt{z_1^2 + \frac{F_L}{\alpha} + z_2}}\right)\frac{\partial}{\partial X}(z_1) + \frac{1}{2\sqrt{z_1^2 + \frac{F_L}{\alpha} + z_2}}\frac{\partial}{\partial X} \tag{A2.4}$$

Since the coefficients of z_1 and z_2 in (A2.4) are positive, its sign depends only on $\frac{\partial}{\partial X}(z_1)$ and $\frac{\partial}{\partial X}(z_2)$. In the following, I compute (A2.4) for variables $T, r, \varphi, \theta, \mu, \wp_{t0}, \omega, |B|\ and\ u_L$, assuming $B < 0$.

Table A2.1 sensitivity of the threshold price of the low-risk firm to the contributing variables

X	$\frac{\partial}{\partial X}(z_2)$	$\frac{\partial}{\partial X}(z_1)$	$\frac{\partial}{\partial X}p_{th}$
r	$\frac{r\left(1-\frac{exp^{-(\mu+r)T}}{\left(\frac{1-\exp^{-(\mu+r)T}}{(\mu+r)T}\right)}\right)+(\mu+r)\left(1-\frac{e^{-rT_1}}{\left(\frac{1-e^{-rT_1}}{rT_1}\right)}\right)}{(1-u_L)\alpha\omega\mathcal{p}_{t0}\mu(1-e^{-rT_1})(1-exp^{-(\mu+r)T})}>0$	$\frac{\frac{\partial}{\partial r}\frac{1}{(1-u_L)\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)}}{-\theta B\left(\frac{1-e^{-rT}}{r}-\frac{e^{-(\varphi+r)T}-1}{-\varphi-r}\right)}-\frac{-\theta B\frac{\partial}{\partial r}\left(\frac{1-e^{-rT}}{r}-\frac{e^{-(\varphi+r)T}-1}{-\varphi-r}\right)}{(1-u_L)\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)}>0$	>0
φ	$\frac{-\theta B\left(\frac{Te^{-(\varphi+r)T}}{-\varphi-r}-\frac{e^{-(\varphi+r)T}-1}{(-\varphi-r)^2}\right)}{(1-u_L)\mu(1-e^{-rT_1})(1-\exp^{-(\mu+r)T})}>0$	0	>0
θ	$\frac{-B\left(\frac{1-e^{-rT}}{r}-\frac{e^{-(\varphi+r)T}-1}{-\varphi-r}\right)}{(1-u_L)\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)}>0$	0	>0
μ	$\frac{\frac{-r}{\mu(\mu+r)}-\frac{Texp^{-(\mu+r)T}}{1-exp^{-(\mu+r)T}}}{(1-u_L)\alpha\omega\mathcal{p}_{t0}\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)}<0$	$\frac{\frac{\partial}{\partial\mu}\frac{1}{(1-u_L)\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)}}{-\theta B\left(\frac{1-e^{-rT}}{r}-\frac{e^{-(\varphi+r)T}-1}{-\varphi-r}\right)}<0$	<0
$\mathcal{p}_{t0}$	$\frac{-1}{(1-u_L)\alpha\omega\mathcal{p}_{t0}{}^2\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)}<0$	0	<0
ω	$\frac{-1}{(1-u_L)\alpha\omega^2\mathcal{p}_{t0}\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)}<0$	0	<0

Table A2.1 sensitivity of the threshold price of the low-risk firm to the contributing variables (cont'd)

X	$\frac{\partial}{\partial X}(z_2)$	$\frac{\partial}{\partial X}(z_1)$	$\frac{\partial}{\partial X}p_{th}$
$\lvert B \rvert$	$\frac{\theta\left(\frac{1-e^{-rT}}{r}-\frac{e^{-(\varphi+r)T}-1}{-\varphi-r}\right)}{(1-u_L)\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)} > 0$	0	>0
u_L	$\frac{1}{(1-u_L)^2\alpha\omega\wp_{t0}\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)} > 0$	$\frac{-\theta B\left(\frac{1-e^{-rT}}{r}-\frac{e^{-(\varphi+r)T}-1}{-\varphi-r}\right)}{(1-u_L)^2\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)} > 0$	>0
T_1	$\frac{-e^{-rT_1}}{(1-u_L)\alpha\omega\wp_{t0}\mu\left(\frac{1-e^{-rT_1}}{r}\right)^2\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)} < 0$	$\frac{\theta B\left(\frac{1-e^{-rT}}{r}-\frac{e^{-(\varphi+r)T}-1}{-\varphi-r}\right)e^{-rT_1}}{(1-u_L)\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-exp^{-(\mu+r)T}}{\mu+r}\right)} < 0$	<0
T	$\frac{\partial}{\partial T}(z_2) = -\frac{e^{-(\mu+r)T}}{(1-u_L)\alpha\omega\wp_{t0}\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-e^{-(\mu+r)T}}{\mu+r}\right)^2} < 0$ $\frac{\partial}{\partial T}(z_1) = -\frac{-\theta B\left(e^{-rT}-e^{-(\varphi+r)T}\right)}{(1-u_L)\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-e^{-(\mu+r)T}}{\mu+r}\right)} - \frac{-\theta B\left(\frac{1-e^{-rT}}{r}-\frac{e^{-(\varphi+r)T}-1}{-\varphi-r}\right)e^{-(\mu+r)T}}{(1-u_L)\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-e^{-(\mu+r)T}}{\mu+r}\right)^2}$ $= \frac{-\theta B\left(\frac{1-e^{-rT}}{rT}-\frac{e^{-(\varphi+r)T}-1}{(-\varphi-r)T}\right)}{(1-u_L)\mu\left(\frac{1-e^{-rT_1}}{r}\right)\left(\frac{1-e^{-(\mu+r)T}}{\mu+r}\right)}\left(\frac{e^{-rT}-e^{-(\varphi+r)T}}{\frac{1-e^{-rT}}{rT}-\frac{1-e^{-(\varphi+r)T}}{(\varphi+r)T}} - \frac{e^{-(\mu+r)T}}{\frac{1-e^{-(\mu+r)T}}{(\mu+r)T}}\right) > 0$ Since the sign of $\frac{\partial}{\partial T}(z_1)$ is positive, the sign of $\frac{\partial p_{th}}{\partial T}$ will be indefinite, but if $\lvert B\rvert \ll 1$, then $z_2 \ll z_1$. Under this condition, I have $p_{th} \cong \sqrt{\frac{F_L}{\alpha} + z_2} + c_L$ which means sign of $\frac{\partial}{\partial T}p_{th}$ depends only on z_2. Therefore, I conclude: $\frac{\partial}{\partial T}p_{th}\begin{cases} < 0 & for\ \lvert -B\rvert \ll 1 \\ indefenite & otherwise \end{cases}$		

Appendix 4-3

In this Appendix, I compute the coefficients of optimal price discussed in proposition 3 where a high-risk firm (H), a low-risk firm (L), and a neutral firm (N) competing on price and demand depends on both price and safety. The parameters used are similar to those defined in equation (1), unless otherwise indicated. Assuming demand has a linear relationship to the rival firm's price and safety, I have:

$$q_i = Q_i - \alpha p_i + \beta(p - p_i) + \gamma s_i - \lambda(s - s_i) \qquad \text{(A3.1)}$$

where $p = \sum_i p_i$, $s = \sum_i x s_i$, $i = H, L\ and\ N$

Using (A3.1), I can then formulate profit of firm i as:

$$\pi_i = p_i q_i = p_i(Q_i - \alpha p_i + \beta(p - p_i) + \gamma s_i - \lambda(s - s_i)) \qquad \text{(A3.2)}$$

Maximizing π_i with respect to p_i I get:

$$p_i^* = \frac{(Q_i + \beta(p - p_i^*) + \gamma s_i - \lambda(s - s_i))}{2\alpha} \qquad \text{(A3.3)}$$

which is equivalent to:

$$(Q_i + \beta(p - p_i^*) + \gamma s_i - \lambda(s - s_i)) = 2\alpha p_i^* \qquad \text{(A3.4)}$$

Summing (A3.3) for the all three firms, I get:

$$\sum_i (Q_i + \beta(p - p_i^*) + \gamma s_i - \lambda(s - s_i)) = \sum_i 2\alpha p_i^* \qquad \text{(A3.5)}$$

which is equivalent to:

$$p = \frac{(Q + \beta 2p + \gamma s - \lambda 2x)}{2\alpha} \qquad \text{(A3.6)}$$

where $Q = \sum_i Q_i$. Substituting (A3.6) into (A3.3), I obtain

$$p_i^* = \mathrm{A}' s_i + \mathrm{B}' s_{-i} + C'_{\mathrm{i}} \qquad \text{(A3.7)}$$

where $\mathrm{A}' = \frac{-2\beta\lambda + (2\alpha - \beta)\gamma}{(2\alpha + \beta)(2\alpha - 2\beta)}$, $\mathrm{B}' = \frac{\beta\gamma - 2\alpha\lambda}{(2\alpha + \beta)(2\alpha - 2\beta)}$, $\mathrm{C}'_{\mathrm{i}} = \frac{\mathrm{Q_i}(2\alpha - \beta) + \beta \mathrm{Q_{-i}}}{(2\alpha + \beta)(2\alpha - 2\beta)}$, $\mathrm{s_{-i}} = s - \mathrm{s_i}$ and $\mathrm{Q_{-i}} = Q - \mathrm{Q_i}$

4.7. **References**

Automotive News, (2010). Asian rivals suffer image dent from Toyota recall. Retrieved from http://www.autonews.com/article/20100308/german_newsletter/3030 79988 /asian-rivals-suffer-image-dent-from-toyota-recall

Baiman, S., Fischer, P. E., & Rajan, M. V. (2000). Information, contracting, and quality costs. *Management Science*, *46*(6), 776-789.

Bakshi, N., & Kleindorfer, P. (2009). Co-opetition and investment for supply chain resilience. *Production and Operations Management, 18*(6), 583-603.

Banker, R. D., Khosla, I., & Sinha, K. K. (1998). Quality and competition. *Management Science*, *44*(9), 1179-1192.

Bettman, J. R., Johnson, E. J., & Payne, J. W. (1991). Consumer decision making. *Handbook of consumer behavior*, *44*(2), 50-84.

Bolton, R. N., & Drew, J. H. (1991). A longitudinal analysis of the impact of service changes on customer attitudes. The Journal of Marketing, 1-9.

Boulding, W., Kalra, A., & Staelin, R. (1999). The quality double whammy. *Marketing Science, 18*(4), 463-484.

Breiter, A., & Huchzermeier, A. (2015). Promotion planning and supply chain contracting in a high-low pricing environment. *Production and Operations Management*, *24*(2), 219.

Chaturvedi, A., & Martínez-de-Albéniz, V. (2011). Optimal procurement design in the presence of supply risk. *Manufacturing & Service Operations Management*,*13*(2), 227-243.

Coffey, B., Mintert, J., Fox, J., Schroeder, T., & Valentin, L. (2005). The economic impact of BSE on the US beef industry: Product value losses, regulatory costs, and consumer reactions.

Dowdell, T. D., Govindaraj, S., & Jain, P. C. (1992). The Tylenol incident, ensuing regulation, and stock prices. *Journal of Financial and Quantitative Analysis, 27*(2), 283-301.

Easton, G. S., & Jarrell, S. L. (1998). The effects of total quality management on corporate performance: An empirical investigation. *The Journal of Business, 71*(2), 253-307.

Gal-Or, E., & Ghose, A. (2005). The economic incentives for sharing security information. *Information Systems Research*, *16*(2), 186-208.

Gordon, L. A., & Loeb, M. P. (2002). The economics of information security investment. *ACM Transactions on Information and System Security (TISSEC), 5*(4), 438-457.

Grafton, S. M., Hoffer, G. E., & Reilly, R. J. (1981). Testing the impact of recalls on the demand for automobiles. *Economic Inquiry*, *19*(4), 694-703.

Gümüs, M. (2014). With or without forecast sharing: Competition and credibility under information asymmetry. *Production and Operations Management, 23*(10), 1732.

Gurnani, H., Ramachandran, K., Ray, S., & Xia, Y. (2014). Ordering behavior under supply risk: An experimental investigation. *Manufacturing & Service Operations Management, 16*(1), 61-75.

Heal, G., & Kunreuther, H. (2007). Modeling interdependent risks. *Risk Analysis, 27*(3), 621-634.

Hendricks, K. B., & Singhal, V. R. (2001). The long-run stock price performance of firms with effective TQM programs. *Management Science, 47*(3), 359–368.

Kamakura, W. A., Mittal, V., De Rosa, F., & Mazzon, J. A. (2002). Assessing the service-profit chain. *Marketing Science, 21*(3), 294-317.

Kim, S. H., & Tomlin, B. (2013). Guilt by association: Strategic failure prevention and recovery capacity investments. *Management Science, 59*(7), 1631-1649.

Kopalle, P. K., & Lehmann, D. R. (2001). Strategic management of expectations: The role of disconfirmation sensitivity and perfectionism. *Journal of Marketing Research, 38*(3), 386-394.

KPMG. (2013). After the Gulf of Mexico oil spill: Developments in oil and gas industry. Retrieved from http://www.kpmg.com /Global/en/IssuesAndInsights /ArticlesPublications /Documents /gulf-of-mexico-oil-spill.pdf

Kunreuther, H., & Heal, G. (2005). Interdependencies in organizations. Organizational Encounters with Risk.

Major, J. A. (2002). Advanced techniques for modeling terrorism risk. *Journal of Risk Finance, 4*(1), 15-24.

Mitra, D., & Golder, P. N. (2006). How does objective quality affect perceived quality? Short-term effects, long-term effects, and asymmetries. *Marketing Science, 25*(3), 230-247.

Oecd.org,. (2015). Retrieved from http://www.oecd.org/officialdocuments/ publicdisplaydocumentpdf/?cote=DSTI/CP(2014)4/FINAL&docLanguage=En

Prabhu, J., & Tellis, G. J. (2000). Do consumers ever learn? Analysis of segment behavior in experimental markets. *Journal of Behavioral Decision Making, 13*(1), 19-34.

Reilly, R. J., & Hoffer, G. E. (1983). Will retarding the information flow on automobile recalls affect consumer demand? *Economic Inquiry, 21*(3), 444-447.

Slovic, P. (1987). Perception of risk. *Science, 236*(4799), 280-285.

Sodhi, M. S. (2005). Managing demand risk in tactical supply chain planning for a global consumer electronics company. *Production and Operations Management, 14*(1), 69-79.

Stoessel, F. (2001). Can we learn to accept risks? In Conference Report, Safety, Risk and Reliability–Trends in Engineering, Malta.

Suddle, S. I., & Waarts, P. H. (2003). The safety of risk or the risk of safety. *Safety and Reliability*, 1511-1518.

Swinney, R., & Netessine, S. (2009). Long-term contracts under the threat of supplier default. *Manufacturing & Service Operations Management, 11*(1), 109.

Treville, S., Schürhoff, N., Trigeorgis, L., & Avanzi, B. (2014). Optimal sourcing and lead-time reduction under evolutionary demand risk. *Production and Operations Management, 23*(12), 2103.

UPI. (2015). UPI Exclusive: No mad cow tests in Wash. Retrieved from http://www.upi.com/Science_News/2004/01/15/UPI-Exclusive-No-mad-cow-tests-in-Wash/14701074196247/

Wang, Y., Gilland, W., & Tomlin, B. (2010). Mitigating supply risk: Dual sourcing or process improvement? *Manufacturing & Service Operations Management*, *12*(3), 489-510.

Xie, G., Yue, W., Wang, S., & Lai, K. K. (2011). Quality investment and price decision in a risk-averse supply chain. *European Journal of Operational Research, 214*(2), 403-410.

Zhuang, J., Bier, V. M., & Gupta, A. (2007). Subsidies in interdependent security with heterogeneous discount rates. *The Engineering Economist, 52*(1), 1-19.

Chapter 5. Conclusions and Implications

5.1.1. Summary and conclusion

This dissertation seeks to help managers recognize, identify, and address "contagion risk", an interdependent risk that is well understood in the finance and marketing areas, but has not yet been adequately studied in the supply chain and operations management domain. The dissertation discusses the concept of contagion in the area of Supply Chain Management for the first time; therefore, some shortfalls might exist, which will be addressed in future works.

The first essay, “Dynamics of Contagion Risk”, theorizes how the failure of rivals in risk management can unfavorably affect other firms’ supply, demand, and operations. Building on the decision making and risk literature, I introduce the notion of "stakeholder identity", which is based on the degree to which a stakeholder’s risk judgment is objective as opposed to subjective. I contend that the closer the identity of the stakeholder is to absolute-lay, the more its judgments and subsequent decisions will be based on biased measures, including (a) signal value of the event, (b) similarity between the focal firm and the liable rival, and (c) trust in the focal firm’s risk management. The results derived from this essay have important implications for supply chain and operations management scholarship, in that it explores contagion risk in the context of decision making processes, highlights the role of stakeholders as agents of risk, and conceptualizes and integrates various types of contagion into a single process model.

The second essay aims to provide empirical evidence on the contagion effect by measuring the average abnormal return of the industry following a product harm recall. My results evidence that in some industries, under certain circumstances, the risk of contagion could be serious, even when the adverse event is familiar and non-extreme, such as product recalls. The findings show, as predicted, that the contagion is more likely to happen when the number of connected casualties to the recall or its signal value is larger or when the abnormal return of the recalling firm is more negative. These findings are important for two reasons. First, they demonstrate the risk of having an unsafe rival; second, they explain why the findings of other research about the contagion effect are mixed.

The third essay, “Management of Contagion Risk”, explores whether and when investment in the safety measures of a high-risk rival is a profitable mitigating strategy. My research results indicate that for a low-risk firm, there is a threshold product price above which such investment would be profitable. The results demonstrate, as expected, that the threshold price is lower when the consequence of contagion is more drastic or when the probability of contagion is higher. The results also show that the sensitivity of the product price of the low-risk firm to the perceived safety of the rival’s product has a reverse relationship to the profitability of the investment. According to my analytical model, a low-risk firm can turn an unprofitable investment into a profitable one by extending the investment horizon; however, the investment is less likely to pay off when firms compete on quantity, as opposed to price. My third essay contributes to the literature by formulating perceived safety and proposing a new co-opetition approach for managing contagion risk.

In summary, my dissertation has identified a new research direction that can generate novel research questions on risk management in supply chain management. Specifically, I introduce the notions of contagion risk, classify contagion risk according to the type of triggering event and form of contagion manifestation, and highlight the underlying role of stakeholder as the agent of contagion risk. On the practical side, my findings help risk managers design more effective risk management strategies in supply chain by integrating the risks that are imposed by rivals and considering the new collaboration opportunities discussed in the third essay.

5.1.2. Managerial Implications

Contagion is a serious threat, not only because it can be triggered by non-severe events, but also because its impact could be quite drastic in extreme cases. Managers should refrain from underestimating the risk of contagion because of its low frequency. Using expected value for assessing the risk of low probability/ high impact type of events markedly distorts their importance relative to high probability/low impact events. For low probability/high impact events, managers should have contingency plans in place to mitigate their maximum impact if they occur.

While all firms are at risk of contagion, low-risk firms should take it more seriously because their safety investments cannot protect them against the reaction of timid stakeholders fearing an event that is happening to a rival.

The fact that larger firms have more resources to invest in their safety measures implies that those firms are generally safer than their smaller rivals. The managers of larger firms are reasonable to deem that their risks of contagion are higher when their industries are dominated by small firms, especially when their stakeholders are highly sensitive to safety issues, such as product/customer, operations/employees, or society/environment safety.

Given that similarity is the key driver of contagion, managers in highly commoditized industries should be more alert to contagion. Differentiating and/or publicizing the differences can help managers mitigate the fear of their lay stakeholders. Transparency and visibility of the supply chain enables stakeholders to identify and recognize the differences between the firm and its rivals; however, managers should be careful about the extent of information they share with their stakeholders. Some information may be misinterpreted by the stakeholders and mislead them. Too much information can confuse the stakeholders and lead to an unfavourable outcome by masking the key information.

It is critical for managers to identify initiation and triggering events to address contagion risk. Managers can recognize the events by reviewing the cases of contagion, not only in their own industries, but also other industries. Some events affect most of the industries in the same manner. For example, counterfeiting is an issue that can hurt all firms when it is detected in a market.

Finally, the fact that contagion can affect all firms in an industry provides an outstanding opportunity for collaboration among rivals. Such collaboration can improve the safety of the industry by increasing the minimum safety requirements, and/or helping rivals that are struggling with safety issues to enhance their safety levels. Such collaboration can lead to safer products and operations, higher safety-investment returns, and ultimately, a more sustainable economy.