EVENT STUDIES IN OPERATIONS AND SUPPLY CHAIN MANAGEMENT: AN OVERVIEW AND TWO EMPIRICAL STUDIES

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Event Studies in Operations and Supply Chain Management: An Overview and Two Empirical Studies

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CERTIFICATE OF ORIGINALITY

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___________________________________ (Signed)

________________Li DING_____________(Name of student)

Dedicated to my grandfather Jinling Zhou,

who obtained his B.A. at the age of sixty in 1998.

Abstract

As the strategic role of operations and supply chain management (OSCM) has been increasingly recognized, the event study method represents one of the most popular methodologies to quantify the impact of OSCM events on firms' shareholder value. Concentrating on the topic of event studies in OSCM, I conduct three studies. The first study is a comprehensive literature review of short-term event studies in OSCM. Analyzing 29 short-term event studies published in renowned OSCM journals between 1995 and 2017, I find that OSCM researchers generally follow the standard procedures in conducting event studies, but pay less attention to some methodological issues ranging from addressing the confounding events to expanding event windows. I provide several recommendations for future event studies in OSCM, such as the opportunity for studying external events in the non-U.S. context, the caution of expanding the event windows, and the need to deal with the self-selection bias.

Considering the research opportunities identified in the first study, the second study employs the short-term event study method to examine the transmission effect of natural disasters across national borders. It is unclear whether the disaster affects the disaster-stricken firms' industry peers located in other areas, especially in other countries. Those industry peers might benefit from the disaster due to the competitive advantage gained over the disaster-stricken firms (competitive effect), or they might suffer from the disaster due to their linkages to the disaster-stricken firms (contagion effect). Based on a natural experiment of Kumamoto earthquakes in Japan in 2016, I find that the earthquakes have a negative impact on the stock returns of the semiconductor manufacturers located in China, suggesting that the contagion effect overweighs the competitive effect. Moreover, the negative impact is more pronounced

for firms with supply chain linkages with Japanese firms, confirming the contagion effect via interfirm linkages. I also find a positive impact among Chinese firms with higher inventory turnover and higher customer concentration, supporting the operational efficiency perspective. Overall, the study reveals the dynamic effects of a natural disaster across national borders, providing important implications for global supply chain management and competition.

While the short-term event study method has been well adopted in the OSCM literature, event studies based on long-term stock returns are relatively scarce, especially for the implementation of new technologies in OSCM. The third study thus employs the long-term event study method to empirically test the impact of 3D printing (3DP) implementation on firm performance in terms of abnormal stock returns. Based on 232 announcements of 3DP implementation made by U.S. public-listed firms between 2010 and 2017, the study shows that firms implementing 3DP enjoy significant higher stock returns compared with their non-implementation industry peers over two years after the implementation. Such stock returns due to 3DP implementation are more pronounced for firms operating in more munificent, more dynamic, and less competitive industry environments, consistent with the operational scope arguments. The study provides important implications for managers to implement 3DP to broaden firms' operational scopes and for researchers to study 3DP from an operational perspective.

Publications Arising from the Thesis

Published journal article:

Lam, H. K., Ding, L., Cheng, T. C. E., & Zhou, H. (2019). The impact of 3D printing implementation on stock returns. *International Journal of Operations & Production Management*, 39, 935-961.

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Conference papers:

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Ding, L., Lam, H. K., Cheng, T. C. E., & Zhou, H. (2018). The Contagion and Competitive Effects across National Borders: Evidence from the 2016 Kumamoto Earthquakes. Paper presented at the 2018 POMS Annual Conference, Houston, Texas, USA.

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Chapter 1 Introduction

1.1 Research background

Over the past few decades, there is growing recognition of the strategic importance of operations and supply chain management (OSCM) in creating shareholder value. OSCM plays a vital role in generating shareholder value through the mechanisms of revenue growth, operating cost reduction, and efficient use of fixed and working capital (Martin and Lynette, 1999). Following this theoretical logic, researchers have conducted various empirical studies to analyze the connection between OSCM and shareholder value, among which the event study method represents one of the most popular methodologies adopted in the literature. By detecting the abnormal equity price changes in response to new information available in the financial market, the event study method enables researchers to quantify the impact of a specific event on a firm's shareholder value (MacKinlay, 1997).

The event study method has been employed by OSCM researchers to investigate various topics such as supply chain disruptions (Hendricks and Singhal, 1997; Zhao *et al*., 2013), environmental management (Jacobs, 2014; Klassen and McLaughlin, 1996), and quality management (Lin and Su, 2013; McGuire and Dilts, 2008). In addition, the event studies in OSCM are evolving as a result of advances in asset pricing models and statistical analysis. The method has been modified to address potential statistical issues specific to different research settings (Fama and French, 2015; Kothari and Warner, 2007). In view of the increased popularity and recent methodological improvements, it is timely to conduct a systematic review of the method to examine how it has been implemented in the OSCM literature and what could be improved to deploy it for future OSCM research (study one).

The research opportunities identified in the literature review of event studies in OSCM lead us to conduct two empirical event studies. First, the review indicates that most researchers focus on internal corporate events in the U.S. context, while less is known about the effects of external events and the non-U.S. context. However, I believe that it is important to investigate the effect of external events, especially in non-U.S. context. Specifically, in the global supply chain, firms are more closely related than ever and can hardly be isolated from the risks originating from external supply chain partners or catastrophic disasters across national borders. In addition, non-U.S. countries, especially developing countries, have been playing the prominent role of being sourcing destinations in global supply chains. Validating the findings from previous studies across different countries is important in advancing our understanding of the global impact of OSCM events. Second, the review shows that most researchers focus on the traditional OSCM topics such as supply chain disruptions, environmental management, and quality management, whereas pay less attention to some emerging OSCM topics such as digital manufacturing. It is imperative to examine the effect of the implementation of digital manufacturing technologies on firms' performance, as the investment in appropriate manufacturing technology has been a critical managerial decision, which not only involves substantial resource commitments, but also demonstrates great potential in creating competitive advantage (Grant *et al.*, 1991). Therefore, I take advantage of the event study method and conduct two empirical studies to address the aforementioned research gaps.

The first empirical study (study two) is a short-term event study concentrating on the transmission effect of natural disasters. On April 14, 2016, a magnitude 6.2 earthquake and two days later a magnitude 7.0 aftershock struck Kumamoto, also known as Japan's Silicon Island, where major semiconductor and electronics manufacturing companies are located. The earthquakes caused production suspensions, facility damages and inventory losses in semiconductor manufacturers located in Kumamoto. Worse still, a number of aftershocks, mudslides, and fires cause server consequences in the entire city including electricity and water outages, highway blocks, infrastructure collapse, cancellation of flights and train services, and resident evacuations (BBC News, 2016). Semiconductor plants are particularly vulnerable to earthquakes due to the requirements of precision manufacturing equipment and clean rooms with very low levels of contaminants and relative long production lead time. According to an announcement made by Sony factory, the full-scale operation was not resumed until late July, which is three and a half months after the initial earthquake. Sony estimated a loss of 115 billion yen (about $1 billion) in profit due to the earthquake (Fortune, 2016).

The OSCM literature has well documented how natural disasters affect disaster-stricken firms' internal operations and supply chains (Altay and Ramirez, 2010; Papadakis, 2006; Sodhi and Tang, 2014). However, little is known about whether and how natural disasters might affect disaster-stricken firms' industry peers located in other areas, especially in other countries. There is an urgent need to examine this important question for several reasons. First, due to the increasing globalization, firms are operating and competing on a global scale (Marucheck *et al*., 2011). Therefore, in addition to addressing direct operations disruptions and supply chain risks due to local natural disasters, firms also need to deal with the possible indirect threats and opportunities arising from overseas natural disasters. Moreover, the impact of a natural disaster on disaster-stricken firms' overseas industry peers is neither intuitive nor straightforward. While those overseas industry peers might benefit from the disaster due to the competitive advantage gained over the disaster-stricken firms (competitive effect), it is also possible that those firms might suffer from the disaster due to their linkages to the disaster-stricken firms (contagion effect). Finally, although the intra-industry contagion and competitive effects have been well studied in the accounting and finance literature (e.g. Gleason *et al*., 2008; Lang and Stulz, 1992; Slovin *et al*., 1999), prior studies have focused on firm-induced events such as bankruptcy filings and accounting restatements in a single country context, rather than natural disasters' impacts across national borders.

While the short-term event study method has been widely adopted by OSCM researchers to assess the stock market reaction within a short time period (e.g. one to three days), the long-term event studies are relatively scarce and examine the stock market reaction over a longer time period, usually up to several years. In the second empirical study (study three), I leverage the long-term event study method to examine how the implementation of 3D printing (3DP) might affect firms' stock market performance. In todays' rapidly-evolving business world, companies are making continuous efforts to identify innovative technologies that suit their market environments and support strategic goals (Grant *et al.*, 1991). 3DP, also known as additive manufacturing, has caught noticeable attention from the business community in recent years (Geissbauer *et al.*, 2017; Ernst & Young, 2016). 3DP is considered to be a disruptive technology that potentially transforms the economics of manufacturing from economy of scale to economy of scope (The Economist, 2017). Former U.S. President Obama highlighted the strategic importance of 3DP by saying that "3DP has the potential to revolutionize the way we make almost everything" (Gross, 2013). An Ernst and Young (2016) global survey shows that 36% of the firms have already implemented or are considering the implementation of 3DP. Originally adopted as a prototyping technology about thirty years ago, 3DP has evolved to be a direct manufacturing technology for the production of components, parts and even end-use products in a variety of industries (Ernst & Young, 2016). For example, GE aviation is using 3DP to build the Advanced Turboprop (ATP), the components of which were reduced from 855 to only 12. The simplified design reduced the weight of the engine by 5%, ultimately saving 20% of fuel and achieving 10% more power than its competitors (Van Dusen, 2017). The transformation grows with a more astonishing speed in the U.S. hearing aid industry, which converted to 100% additive manufacturing in less than 500 days (d'Aveni, 2015).

Despite the great progress of 3DP within the past few years, little empirical evidence has been provided of its impact on firm performance. Most previous research of 3DP concentrates on its technological features and industrial applications (Lam *et al.*, 2002; Ventola, 2014; Williams *et al.*, 2010). Recently, the business implications of 3DP have received greater attention, though the majority of the studies only provide qualitative discussions of its benefits, limitations, implementation challenges, and socio-economic impact (Chan et al., 2018; Huang *et al.*, 2012; Petrick and Simpson, 2013; Weller *et al.*, 2015; Jiang *et al.*, 2017; Khorram Niaki and Nonino, 2017; Shukla *et al.*, 2018; Eyers *et al.*, 2018). While some researchers have started to examine the antecedents of 3DP adoption using surveys (Schniederjans, 2017; Wang *et al.*, 2016; Rojo *et al.*, 2018), identify the implementation challenges (Chan et al., 2018), or investigate the business models enabled by 3DP using computer modeling and simulation (Jia *et al.*, 2016), there is a lack of empirical research investigating the impact of 3DP implementation on performance at the firm level.

1.2 Research objectives

The thesis seeks to summarize the current knowledge of event studies in OSCM and, more importantly, identify emerging research opportunities and provide methodological guidelines for OSCM researchers interested in applying the methodology. In addition, the thesis aims to take advantage of the event study method to address the emerging research opportunities identified, and to shed light on how some underexplored OSCM events might affect firms' financial performance.

In the first study, I conduct a comprehensive literature review of short-term event studies in OSCM. Specifically, the review aims to address the following research questions: (1)What are the current practices of short-term event studies in OSCM? What are the topics examined by the OSCM researchers? What steps do the researchers follow to conduct short-term event studies? (2) What are the important methodological issues often ignored by OSCM researchers? (3) What are the emerging research opportunities in event studies in OSCM? What are the methodological recommendations for conducting future event studies?

In the second study, in order to investigate the transmission effect of nature disasters, I employ the short-term event study method and focus on the 2016 Kumamoto earthquakes. The study aims to address the following research questions: (1) What is the overall stock market reaction of Chinese semiconductor firms after the Kumamoto earthquakes? Do negative contagion effect and positive competitive effect coexist in the overall transmission effect? (2) What types of Chinese semiconductor firms are more likely to suffer or reap benefits from the earthquakes? In other words, how does the effect vary across firms with different supply chain characteristics including supply chain linkage, inventory turnover, and customer concentration?

In the third study, in order to quantify the effect of the implementation of digital manufacturing technologies on firms' financial performance, I employ the long-term event study method and focus on the implementation of 3DP. Specifically, the study aims to address the following research questions. (1) What is the effect of the implementation of 3DP on firms' long-term stock market performance? (2) How does the effect vary across firms in the industries with different levels of munificence, dynamism, and competition?

1.3 Research methodology

The first study is a systematic literature review of short-term event studies in OSCM. Specifically, I take the following three steps to conduct the review. First, I started the data collection process by searching the single keyword "event study" in the journals listed as the 13 "leading" OSCM journals included in the Korea University Business School (KUBS) Worldwide Business Ranking; I examined all the papers generated from the preliminary search process and only included those actually adopting the event study method; I excluded other types of event studies such as long-term event studies based on abnormal stock returns or abnormal operating performance; I read the hypotheses and results sections of all the searched papers, and further filtered the search results to ensure that the event study method is employed to investigate OSCM topics directly; I cross-checked the references cited in the papers to ensure no qualified articles were missed out from my analysis. The data collection process generates a list of 29 short-term event studies published between 1995 and 2017. Second, I summarized the basic steps for conducting a short-term event study. I also provided a detailed explanation of each step and review the current practices of conducting short-term event studies in OSCM. Third, based on the review of the current practices, I uncovered several methodological issues that need further attention. I identified several research design issues regarding event identification, event window selection, confounding effect, self-selection bias, estimation model, significance test, and time and industry clustering, and suggested ways to address them, thus providing OSCM researchers with practical recommendations for conducting future short-term event studies.

The second study is a short-term event study based on a natural experiment in which a series of earthquakes struck Kumamoto, Japan's Silicon Island, in April 2016. While it is intuitively compelling that supply chain disruptions have negative impacts within a specific company, it remains unsettled as to the transmission effects on external parties. Negative or positive transmission effects have been documented for firms having cooperative or competitive supply chain relationships with initially-disrupted firms (Barrot and Sauvagnat, 2016; Erwin and Miller, 1998; Ferstl *et al*., 2012). I relied on the contagion and competitive effect discussed in accounting and finance literature (Bhabra *et al*., 2011; Prokopczuk, 2010; Erwin and Miller, 1998), and postulated that the overall transmission effect of Kumamoto earthquakes on Chinese semiconductor industry is a combination of the two competing effects. Based on the supply chain disruption literature and operational efficiency perspective, I further proposed three supply chain characteristics including supply chain linkage, inventory turnover, and customer concentration, which might moderate the transmission effect. To examine the transmission effect, I conducted a short-term event study to quantify the overall transmission effect, and a subsequent ANOVA to discern the two competing effects within the overall transmission effect. Additionally, I conducted a cross-sectional regression analysis to investigate the moderating effect of the proposed three supply chain characteristics. I also performed additional analysis over different event windows to test the robustness of the results.

The third study is a long-term event study based on the announcements of the implementation of 3DP technology by U.S. public-listed firms between 2010 and 2017. The study seeks to theoretically hypothesize and empirically test the effect of 3DP implementation on firm performance in terms of abnormal stock returns. It further explores how the stock returns due to 3DP implementation vary across different industry environments. This study adopts an operational perspective to argue that 3DP enables firms to broaden their operational scopes, leading to positive stock returns. It also develops hypotheses underpinning the fit between 3DP-enhanced operational scopes and firms' operating environments. To quantify the effect of the implementation of 3DP, I conducted a long-term event study based on the 232 announcements of 3DP implementation made by U.S. public-listed firms between 2010 and 2017. I further employed cross-sectional regression analysis to examine the moderating effect of industry environments including the level of munificence, dynamism, and competition. I also performed additional analysis over different event windows and matching criterion to test the robustness of the findings.

1.4 Research importance

The first study of the literature review is important in several ways. First, it serves as a practical guide for OSCM researchers interested in employing the short-term event study method in their research. I document the detailed steps of conducting a short-term event study and discuss some common issues encountered in each step, thus enabling OSCM researchers to have a better understanding of how a short-term event study should be conducted. Moreover, to the best of my knowledge, this is the first comprehensive review of event studies in the OSCM literature. Given the increased prevalence of event studies in OSCM, it is imperative to provide an overview of the current state of knowledge and best practices adopted in the OSCM literature. Finally, my research identifies several important research design issues that are often ignored by researchers of past short-term event studies in OSCM, as well as some emerging opportunities specific to the OSCM context, so helping advance the adoption of the event study method for OSCM research.

The short-term event study of the earthquakes contributes to the OSCM literature in several ways. First, although prior studies have well documented how natural disasters affect disaster-stricken firms' operations and supply chains (Altay and Ramirez, 2010), little is known about the possible impacts on the disaster-stricken firms' industry peers located in other areas. My research fills this gap by empirically examining the effects of the Kumamoto earthquakes on the disaster-stricken firms' industry peers in China. In addition to the overall effects, I further reveal how such effects vary across those Chinese firms with different firm and supply chain characteristics, thus providing important implications for global supply chain management and competition. Moreover, I extend the concepts of contagion and competitive effects to study the dynamic impacts of earthquakes across national borders. My research is different from prior accounting and finance studies focused on the intra-industry contagion and competitive effects due to firm-induced events in a single country context (Gleason *et al*., 2008; Lang and Stulz, 1992), and thus may inspire OSCM researchers to explore the possible cross-border contagion and competitive effects due to external events such as natural disasters or policy changes. Finally, I adopt the operational efficiency perspective to examine the determinants of competitive effects in the earthquake context. The operational efficiency perspective adopted in the research thus offers a fruitful theoretical framework for future research to study the competitive effects due to exogenous operations disruptions in general and natural disasters in particular.

The long-term event study of 3DP makes several important contributions. First, the study is one of the first research efforts that empirically examine the impact of 3DP implementation on firm performance in terms of abnormal stock returns. The empirical evidence advances practitioners' understanding of the business value of 3DP. Second, I extend the research on manufacturing capabilities beyond the "structure-conduct-performance" framework which regards environmental conditions as leading factors of manufacturing capabilities. Instead, I emphasize the role of industry environments in moderating the value of enhanced capability due to broadening operational scope with 3DP. My study suggests that before making investment decisions, managers may wish to consider the industry support and industry requirement in estimating how much business value can be expected from 3DP implementation. Third, the study reconciles the mixed results of the relationship between broadening operational scope and firm performance with emphasis on environmental fit. My study takes advantage of the context of 3DP implementation and empirically demonstrates that the benefit of broadening operational scope is dependent on the fit with the environmental conditions.

1.5 Research framework

Under the general topic of event studies in OSCM, I first conduct a comprehensive literature review (Study 1) to summarize the current practices of event studies in OSCM, and based on which I propose several emerging research opportunities and methodological recommendations for future studies. The research opportunities identified in the literature review (Study 1) motivate the two subsequent empirical event studies (Study 2 and 3). Specifically, the literature review indicates that most of the existing event studies in OSCM focus on internal events (97%), U.S. context (83%), and traditional OSCM technologies (e.g., Customer Relationship Management systems and IT-based knowledge management), while less is known about external events, the context of developing countries, and emerging manufacturing technologies such as digital manufacturing. Despite the scarcity, it is important to take advantage of the event study method and address such research gaps to keep up with the rapid development in OSCM discipline. First, as the supply chain network is becoming more globalized, any event occurring in one link of a global supply chain potentially creates a widespread effect across borders. Second, digital manufacturing technologies such as 3DP and block chain are gaining great attention, and practitioners are eager to evaluate the potential economic value of these emerging technologies to facilitate their business decisions. Therefore, these research opportunities identified in the literature review (Study 1) motivate the choice of research topics of the subsequent two empirical event studies (study 2 and 3).

In addition to the identification of research topics, the literature review (Study 1) also provides methodological guidelines for the subsequent two empirical studies (Study 2 and 3). I follow the standard procedures summarized in the literature review, and address the commonly ignored methodological issues identified in the literature review when conducting the two empirical event studies. For example, as emphasized in the literature review, justifications of the choice of event windows are not consistently provided in the existing event studies; inadequate attention has been paid to eliminating confounding effect; significance analysis of the abnormal returns should be adjusted to take into account the potential bias due to industry and time clustering. In the short-term event study (Study 2), I do not only provide justifications of the five-day event window, but also conduct sensitivity analysis over multiple event windows to enhance the robustness of results. 11 firms were eliminated due to the confounding announcements released during the event period. The portfolio approach (Brown and Warner, 1985) was adopted as significance test to address the correlations between firms within a single industry and date. In the long-term event study of the 3DP implementation (Study 3), one challenge is that there is only limited empirical investigations on the implementation of 3DP, and there is a lack of objective standard on the choice of 3DP implementation time periods. To overcome this challenge, I rely on the content of the announcements to identify appropriate event windows. I carefully read through all the announcements, traced the history about each firm's 3DP implementation activities, and identified the timeline of each implementation if it is available in the announcements. To test the sensitivity of the results, multiple event windows are tested and the results are generally consistent across event windows. Moreover, in terms of the benchmark selection, three combinations of firm-level characteristics and propensity score matching are adopted. The results remain consistent across different matching techniques. Figure 1.1 summarizes the research framework and the linkages between three studies in the thesis.

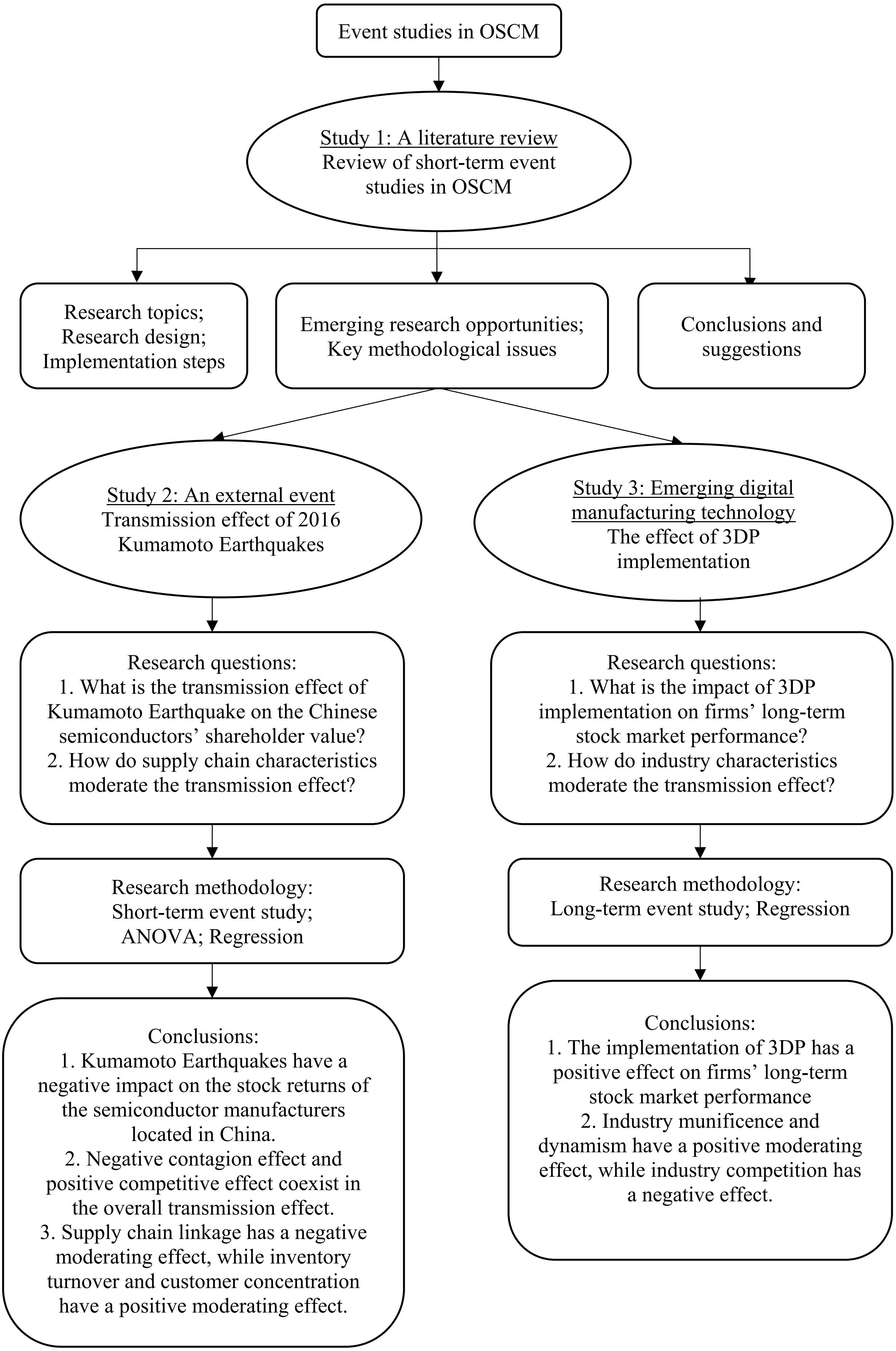

Figure 1.1 Research framework

Chapter 2 Study One: A Literature Review of Short-term Event Studies in OSCM[1]

2.1 Literature review

The first event study reported in the literature was perhaps conducted by James Dolley in 1933. Based on a sample of 95 stock splits from 1921 to 1931, Dolley (1933) investigated the nominal stock price changes at the time of the stock splits. Modern event studies were initiated in the two seminal works of Ball and Brown (1968) and Fama *et al*. (1969). Modern event studies are developed into different categories in terms of the event window length and performance measurement. Long-term event studies detect abnormal stock returns over a period normally ranging from one to eight years with calendar-time portfolio abnormal return (CTAR) or buy-and-hold abnormal return (BHAR) (Barber and Lyon, 1997; Lyon *et al*., 1999), while short-term event studies examine abnormal stock returns over a maximum window length of 40 days (Brown and Warner, 1985; MacKinlay, 1997). A broader definition of event study goes beyond the scope of stock market reaction as it also measures other firm-level outcomes such as operating performance (Barber and Lyon, 1996). In parallel with advances in asset pricing models and statistical analysis, the event study method is still evolving to account for possible deviations from the fundamental assumptions. However, the gist of modern event studies remains the same, which is measuring the significance of sample securities' mean and cumulative abnormal returns around an event period (Kothari and Warner, 2007).

[1] This chapter was published in *International Journal of Production Economics, Volume 200, June 2018, Page 329-342.*

Originally applied in accounting and finance, the event study method has expanded its application to virtually all the business disciplines including management, information systems, marketing, operations and supply chain management (MacKinlay, 1997; McWilliams and Siegel, 1997). For example, in the marketing literature, researchers adopt the event study method to examine the financial impact of such marketing events as new product release, CMO appointment, brand acquisition and disposal, and Internet channel addition (Sorescu *et al*., 2017), while events attracting information systems researchers' attention include IT outsourcing, IT investment, IT excellence award, software vulnerability, and security breaches (Konchitchki and O'Leary, 2011)

Table 2.1 Previous literature reviews of the event study method

Discipline	Literature review	Articles	Time range	Source	Content description
Accounting and finance	MacKinlay (1997)	N.A.	N.A.	N.A.	1. Procedure for conducting an event study; 2. Measuring the expected returns; 3. Making statistical inferences; 4. Analysis of the power of an event study; 5. Nonparametric approaches; 6. Cross-sectional regression approach; 7. Further issues relating to event study design.
	Binder (1998)	N.A.	N.A.	N.A.	1. Hypothesis testing; 2. Different benchmarks for the normal rate of return; 3. The power of the methodology in different applications; 4. The modeling of abnormal returns as coefficients in a regression framework.
	Corrado (2011)	N.A.	N.A.	N.A.	1. Outlines the econometric skeleton of an event study; 2. A survey of results obtained from studies of event study methodology; 3. Problem of event-induced variance and attempts to cope with the problem.
	Kothari and Warner (2007)	565	1974-2005	*Journal of Business*, *Journal of Finance*, *Journal of Financial Economics*, *Journal of Financial and Quantitative Analysis*, *Review of Financial Studies*	1. Describe the changes in event study methodology over time; 2. Procedures for conducting an event study, properties of the event study test; 3. Critical issues of conducting long-horizon event studies.
Management	McWilliams and Siegel (1997)	29	1986-1995	*Academy of Management Journal*, *Strategic Management Journal*, *Journal of Management*	1. Assumptions and research design issues of event studies in Management literature; 2. Replications of previous event studies.
Information systems	Konchitchki and O'Leary (2011)	over 50	N.A.	N.A.	1. A survey of research that uses event study methodologies; 2. Key parameters and concerns associated with implementation of event studies; 3. Remarks on key event study modeling issues and recommendations to researchers.
Marketing	Sorescu *et al.* (2017)	over 40	2000-2015	*Journal of Marketing Research*, *Journal of Marketing*, *Journal of the Academy of Marketing Science*, *Marketing Science*	1. Theoretical foundations and research design of event studies used in the marketing literature; 2. Interpretation of event studies; 3. Event study implementations and alternative methods; 4. Guidelines for future research.

Table 2.1 summaries previous literature reviews of event studies in different business disciplines. It indicates that the literature reviews in accounting and finance emphasize the econometric and statistical fundamentals and provide guidelines for applications in other fields. For instance, MacKinlay (1997) and Binder (1998) reviewed the use of event studies in finance, outlined the standard procedures for conducting event studies, and discussed the power of analysis and the subsequent regression analysis. Corrado (2011) reviewed variations in the basic short-term event study method to adjust for non-normality, event-induced volatility, and cross-sectional weighting. Kothari and Warner (2007) conducted a comprehensive survey of over 500 studies published in five of the top finance and accounting journals from 1974 to 2005. They found that the properties of the event studies reviewed were different depending on the time period and sample firm characteristics. They also indicated that, compared with short-term event studies, long-term event studies suffer from several important limitations.

As the event study method evolves over time, its statistical properties become well-defined and its applications are widely acknowledged. Literature reviews in other business disciplines place a greater emphasis on the research design issues and economic interpretations of the study results. McWilliams and Siegel (1997) conducted a survey of 29 event studies in three of the top management journals from 1986 to 1995. They discussed several concerns about the validity of the assumptions and research design issues. By replicating three studies in management with alternative research designs, they called for adequate attention towards the aforementioned concerns. They also indicated that the abnormal returns only reflect the effect on the shareholder wealth, rather than the welfare of all the stakeholders. Konchitchki and O'Leary (2011) examined the use of the event study method in over 50 information systems studies.

They focused on the research design issues without investigating the actual results and conclusions in specific studies. Sorescu *et al*. (2017) identified over 40 event studies published in the marketing journals included in the list of *Financial Times*' 50 top business journals. In addition to research designs, their review examines interpretations of event studies as well. They provided economic inferences from the event studies by summarizing the main findings and common determinants of abnormal returns in the marketing literature.

Consistent with other fields, OSCM has witnessed a growth in employing event study as a viable research method. However, to the best of my knowledge, there is no literature review of event studies in OSCM. One related study performed by Min and Wei (2013) reviews the literature linking supply chain management (SCM) and firm-level financial performance. Based on 49 research articles published between 1990 and 2011, they summarized the empirical studies conducted using various research methods, including structural equation modelling, event study, correlation analysis, and multivariate regression. Aiming to provide a better understanding of how SCM affects financial performance, their review is topic-centric and is comprehensive in terms of research methodology without specializing in event studies. Therefore, in order to summarize the current knowledge of short-term event studies in OSCM and to provide guidelines for OSCM researchers interested in applying the methodology, I conduct this literature review and make recommendations on its proper use.

2.2 The scope of this research

Event studies in OSCM can be classified according to short-term or long-term event windows, along with various performance measurements, such as stock returns (Brandon-Jones *et al*., 2017), accounting-based operating performance (Lo *et al*., 2009;

Tang *et al*., 2016), plant productivity (Gopal *et al*., 2013), safety violations (Lo *et al*., 2014), and flight delays (Nicolae *et al*., 2016). My study focuses on the event studies measuring the short-term stock market reactions for the following reasons. First, among the different types of event studies, the short-term approach is the earliest, as well as the most widely adopted method in OSCM (Hendricks and Singhal, 1996; Hendricks *et al*., 1995; Klassen and McLaughlin, 1996), providing enough representative samples for us to analyze how the method is implemented in the literature. Second, it is difficult to incorporate both short-term and long-term event studies in a single review paper due to their fundamental differences in theoretical assumptions and methodological execution. Specifically, short-term event studies are based on the Efficient Market Hypothesis (Malkiel and Fama, 1970), assuming that any new information available in the stock market will be reflected almost immediately in security price changes (MacKinlay, 1997). In contrast, long-term event studies are proposed based on the belief that stock prices could partially anticipate and slowly adjust to new available information. In terms of execution, elimination of confounding announcements is a vital step in short-term event studies, whereas this step is unnecessary and impractical in long-term event studies (Sorescu *et al*., 2017). In addition, short-term event studies are less sensitive to the estimation model of normal returns and assumptions of independence in most cases (Kothari and Warner, 2007). On the contrary, the precision of estimation is important in long-term event studies. Even a small error in risk adjustment of estimation models may ultimately lead to huge differences in cumulative abnormal returns, which are aggregated over a long time period (Kothari and Warner, 2007). Therefore, in consistency with the literature reviews of event studies in other fields (Corrado, 2011; Konchitchki and O'Leary, 2011; MacKinlay, 1997), I focus the review on short-term event studies in OSCM to provide clearer and more specific analysis and discussion.

2.3 Data

To identify short-term event study papers in OSCM for this review, I rely on a list of 13 "leading" OSCM journals included in the Korea University Business School (KUBS) Worldwide Business Ranking. The 13 journals are *Computers and Operations Research*, *Decision Sciences*, *European Journal of Operational Research*, *IIE Transactions*, *International Journal of Operations and Production Management*, *International Journal of Production Economics*, *Journal of Operations Management*, *Journal of Supply Chain Management*, *Journal of the Operational Research Society*, *Management Science*, *Manufacturing and Service Operations Management*, *Operations Research*, and *Production and Operations Management*.

I conducted the data collection process in five steps. First, I searched the single keyword "event study" in the aforementioned journals to generate a list of papers fitting the research objective. This single keyword approach could ensure a more comprehensive coverage of event studies about different OSCM topics, which is different from past review studies that are concerned with a specific OSCM topic such as green supply chain management (Srivastava, 2007) and rely on a combination of various keywords. Second, I examined all the papers generated from the preliminary search process and only included those actually adopting the event study method. In particular, I read the methodology section of each paper and excluded those mentioning the event study method but deploying other methods such as content analysis (e.g., Montabon *et al*., 2007) and regression analysis (e.g., Bayus *et al*., 2003; Ramdas *et al*., 2013). Third, as the review focused on short-term event studies based on abnormal stock returns, I excluded other types of event studies such as long-term event studies based on abnormal stock returns (e.g., Hendricks and Singhal, 2001; 2005) or abnormal operating performance (e.g., Corbett *et al*., 2005; Lo *et al*., 2012). Fourth, I further filtered the search results to ensure that the event study method is employed to investigate OSCM topics directly. Specifically, after reading the hypotheses and results sections of all the searched papers, I excluded the event study by Fosfuri and Giarratana (2009) that investigated stock market reactions to new product announcements and filed trademarks, which are more related to marketing rather than OSCM. Finally, I cross-checked the references cited in the papers to ensure no qualified articles were missed out from the analysis.

Table 2.2 Publication journals and years of short-term event studies in OSCM

Classification	Number of papers	Event studies
Panel A: Publication Journal		
JOM	8	Brandon-Jones *et al*. (2017), Hendricks and Singhal (2003), Hendricks *et al*. (1995), Hendricks *et al*. (2009), Jacobs and Singhal, (2017), Jacobs *et al*. (2010), Mitra and Singhal (2008), Modi *et al*. (2015)
IJPE	7	Lam *et al*. (2016), Lin and Su (2013), McGuire and Dilts (2008), Ni *et al*. (2014), Wood *et al*. (2017), Yang *et al*. (2014), Zhao *et al*. (2013)
MS	6	Girotra *et al*. (2007), Hendricks and Singhal (1996), Hendricks and Singhal (1997), Kalaignanam *et al*. (2013), Klassen and McLaughlin (1996), Thirumalai and Sinha (2011)
POM	4	Ba *et al*. (2013), Jacobs and Singhal (2014), Jacobs (2014), Xia *et al*. (2016)
IJOPM	2	Dam and Petkova (2014), Paulraj and Jong (2011)
DS	1	Sabherwal and Sabherwal (2005)
EJOR	1	Nicolau and Sellers (2002)
Panel B: Publication year		
1995-1999	4	
2000-2004	2	
2005-2009	5	
2010-2014	12	
2015-2017	6	
Total	29	

DS = Decision Sciences, *EJOR = European Journal of Operational Research*, *IJOPM = International Journal of Operations and Production Management*, IJPE = *International Journal of Production Economics*, *JOM = Journal of Operations Management*, *MS = Management Science*, *POM = Production and Operations Management.*

Table 2.2 lists the final 29 short-term event studies included in this review. The papers were published between 1995 and 2017 in *Journal of Operations Management* (28%), *International Journal of Production Economics* (24%), *Management Science* (21%), *Production and Operations Management* (14%), *International Journal of Operations and Production Management* (7%), *Decision Sciences* (3%), and *European Journal of Operational Research* (3%). In addition, from the publication years, I find that short-term event studies in OSCM are emerging and developing. There were only six papers (20%) published in the first ten years from 1995 to 2004, but 18 papers (62%) were published in the recent eight years from 2010 to 2017.

2.4 Current practices of short-term event studies in OSCM

Figure 2.1 summarizes the basic steps for conducting an short-term event study (MacKinlay, 1997), which include: (1) identify an event of interest; (2) define the event window and justify the choice of the window length; (3) collect the sample and eliminate confounding events; (4) predict normal returns with an estimation model; (5) calculate the abnormal returns, aggregate them over the event windows and test their significance; and (6) explain the cross-sectional variations in the abnormal returns. I provide a detailed explanation of each step below and review the current practices of conducting short-term event studies in OSCM.

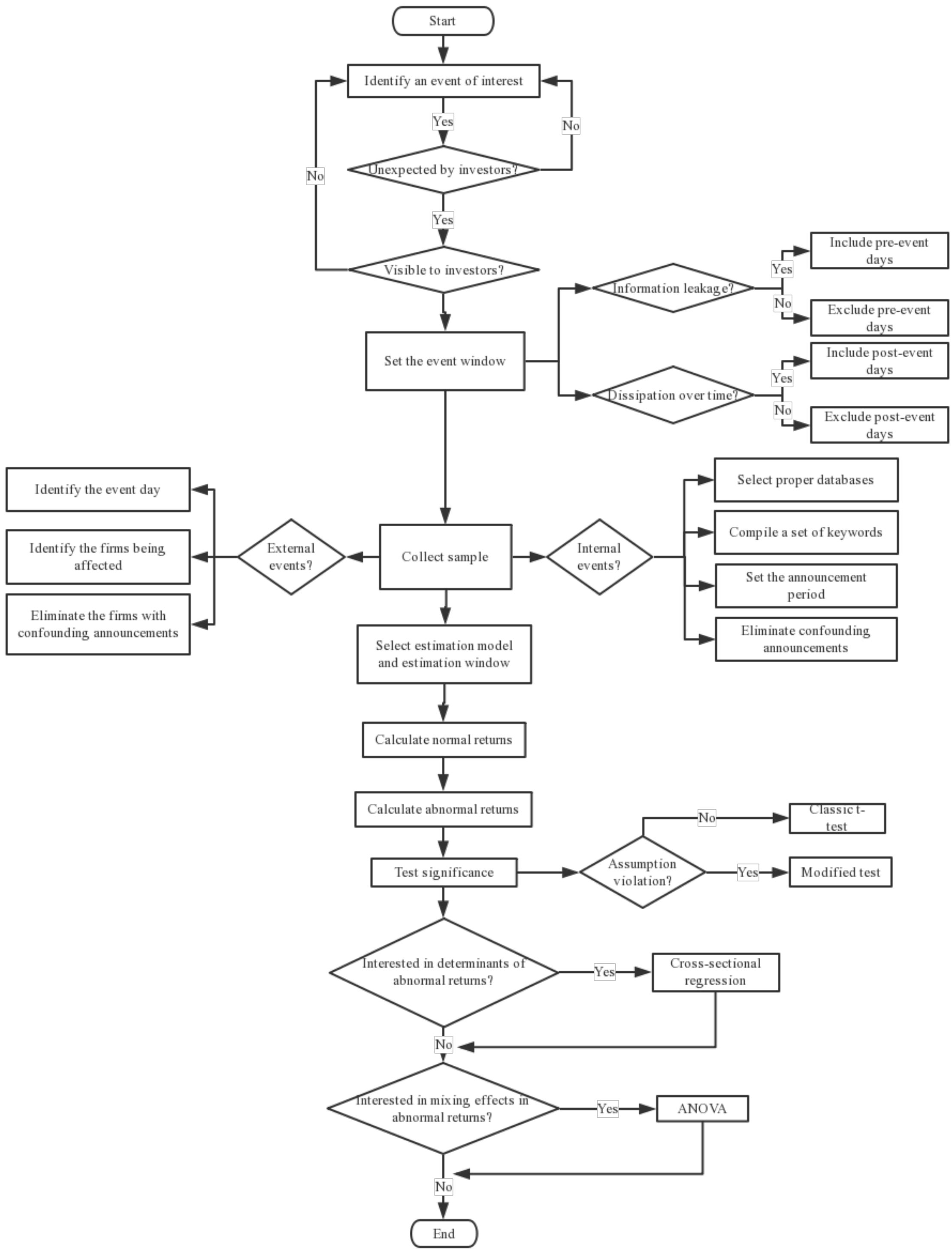

Figure 2.2 Steps of conducting a short-term event study

2.4.1 Identify an event of interest

Firms and other third parties often make announcements about significant activities occurring in all the aspects of the firms' internal operations and supply chain management, offering rich opportunities for researchers to identify events of interest for their research. As shown in Table 2.3, the topics investigated by short-term event studies in OSCM include supply chain disruptions (31%), environmental management (24%), quality management (14%), R&D projects (10%), sourcing strategies (7%), capacity expansion (4%), information technology management (4%), supply chain integration (3%), and purchasing and sales contract (3%).

Table 2.3 Summary of short-term event studies in OSCM

Event Study	Journal	Topic	Event Type	Event	Event Period	Data Source	Confounding Announcements
Ba *et al*. (2013)	*POM*	Environmental management	Internal	Environment initiatives and innovation (Green Vehicle Innovation)	1996-2009	Factiva	Adjacent announcements in (-2, +2)
Brandon-Jones *et al*. (2017)	*JOM*	Sourcing strategy	Internal	Reshoring	2006-2015	Factiva, Google News, the website of the Reshoring Initiative	Any announcements released on the prior trading day after stock market closure or on the announcement date itself
Dam and Petkova (2014)	*IJOPM*	Environmental management	Internal	Environmental supply chain sustainability program	2005-2011	BW, Google	Not reported
Girotra *et al*. (2007)	*MS*	R&D projects	Internal	R&D projects	1994-2004	R&D Insight database developed by ADIS international (the pharmaceutical industry)	Not reported
Hendricks and Singhal (2003)	*JOM*	Supply chain disruptions	Internal	Supply chain glitches	1989-2000	*WSJ*, DJNS	Earnings pre-announcements where supply chain glitches were mentioned as one of the many factors affecting earnings expectations
Hendricks and Singhal (1996)	*MS*	quality management	Internal	Quality award	1985-1991	TRND, DJNS	Any other announcements in (-2, +2)
Hendricks and Singhal (1997)	*MS*	Supply chain disruptions	Internal	Product introduction delay	1984-1991	TRND, DJNS	Not reported
Hendricks *et al*. (1995)	*JOM*	Capacity expansion	Internal	Capacity expansion	1979-1990	TRND, WSJ, PR Newswire	Earnings or any other types of announcements (dividends, change in CEO, product recalls, product delays, lawsuits, new product introductions, etc.) made in (-2, +2)
Hendricks *et al*. (2009)	*JOM*	Supply chain disruptions	Internal	Supply chain disruptions	1989-1998	*WSJ*, DJNS	Announcements that mention the supply chain disruption as one of many issues

Event Study	Journal	Topic	Event Type	Event	Event Period	Data Source	Confounding Announcements
Jacobs and Singhal (2014)	*POM*	R&D projects	Internal	Product development restructuring	2002-2011	DJNS, *WSJ*	Not reported
Jacobs and Singhal (2017)	*JOM*	Supply chain disruptions	External	Catastrophic disaster	N.A.	N.A.	Any announcements over the event window
Jacobs *et al*. (2010)	*JOM*	Environmental management	Internal	Environmental initiatives and environmental awards	2004-2006	BW*, Chicago Tribune, Denver Post, Dow Jones Business News, Financial Times, Houston Chronicle, Los Angeles Times, New York Daily News, Philadelphia Inquirer,* PR Newswire (US) *The New York Times, WSJ, USA Today, Washington Post*	Any other announcements in (-2, +2)
Jacobs (2014)	*POM*	Environmental management	Internal	Voluntary emissions reduction	1990-2009	*WSJ*, PR Newswire, BW, DJNS	Multiple VER announcements for the same firm within 20 trading days; VER announcements that also contain earnings or other material information
Kalaignanam *et al*. (2013)	*MS*	Sourcing strategy	Internal	CRM outsourcing	1996-2006	LexisNexis, Factiva, ACSI	Not reported
Klassen and McLaughlin (1996)	*MS*	Environmental management	Internal	Environmental management	1985-1991	Nexis	Financial and management announcements identified from the NEXIS financial database in (-1, +1)
Lam *et al*. (2016)	*IJPE*	Environmental management	Internal	Environmental initiatives	2005-2014	WiseNews (Shanghai Securities News, China Securities Journal, and Secutimes)	Announcements such as key executive appointments and annual earnings announcements
Lin and Su (2013)	*IJPE*	Quality management	Internal	Quality award	1991-2009	N.A.	Not reported
McGuire and Dilts (2008)	*IJPE*	Quality management	Internal	ISO9000	1999-2002	BW, Dow Jones Business News, DJNS, PR News, PR Newswire, Reuters News, *WSJ*	Announcements with more than one article in the Wall Street Journal in (-2, +2)

Event Study	Journal	Topic	Event Type	Event	Event Period	Data Source	Confounding Announcements
Mitra and Singhal (2008)	*JOM*	Supply chain integration	Internal	Supply chain integration	2000-2001	*WSJ*, Dow Jones Newswire, BW, PR NewsWire	Not reported
Modi *et al*. (2015)	*JOM*	Supply chain disruptions	Internal	Service failure	2005-2010	Identity Theft Resource Center (ITRC) (report information security breaches), Factiva	A quarterly earnings release, a merger/acquisition, a change of a CEO or CFO, a debt restructuring, or an unexpected dividend change within two trading days of the event date
Ni *et al*. (2014)	*IJPE*	Supply chain disruptions	Internal	Product recall	2000-2009	Consumer Product Safety Commission (CPSC)	Not reported
Nicolau and Sellers (2002)	*EJOR*	Quality management	Internal	ISO9000	1993-1999	Baratz (cover Spanish newspapers)	News items within whose windows a public offer of stock acquisition, a take-over or any large purchases of shares were announced
Paulraj and Jong (2011)	*IJOPM*	Environmental management	Internal	ISO14001	1996-2008	BW, PR NewsWire	Potentially newsworthy announcements, such as dividend declarations and earnings announcements in (-5, +5)
Sabherwal and Sabherwal (2005)	*DS*	IT	Internal	IT governance (IT-based knowledge management efforts)	1995-2002	LexisNexis (BW, PR Newswire, *The New York Times*, *The San Francisco Chronicle*, *USA Today*)	Earnings, dividends, merger, acquisition, divestiture, or change in top management announcements in (-2, +2)
Thirumalai and Sinha (2011)	*MS*	Supply chain disruptions	Internal	Product recall	2002-2005	FDA, Lexis-Nexis, Google News archives	Not reported
Wood *et al*. (2017)	*IJPE*	Supply chain disruptions	Internal	Product recall	1979-2016	Consumer Product Safety Commission (CPSC) database, Factiva	Not reported
Xia *et al*. (2016)	*POM*	R&D projects	Internal	Product design awards	1998-2011	Factiva, LexisNexis	Not reported
Yang *et al*. (2014)	*IJPE*	Purchasing/sales contract	Internal	Purchasing/sales contract	2001-2012	Shanghai SE website, Shenzhen SE website	Not reported
Zhao *et al*. (2013)	*IJPE*	Supply chain disruptions	Internal	Product recall	2002-2011	China Infobank database, Chinese automobile recall website	Not reported

WSJ = *The Wall Street Journal*, DJNS = Dow Jones News Service, TRND = Trade and Industry Index, BW = Business Wire

Although the topics of event studies in OSCM vary, most of them are focused on internal corporate events that are within specific firms or their supply chains, with only one of the 29 papers I reviewed examining an event external to the firms concerned. Specifically, only the recent event study conducted by Jacobs and Singhal (2017) investigates the impact of an external event in terms of the Rana Plaza disaster in Bangladeshi on the shareholder value of global apparel retailers.

The majority of the OSCM literature studies events in the U.S. context, with only five of the 29 studies (17%) being in the non-U.S. context. Specifically, of these five non-U.S. based studies, there is one study about the impact of quality certification on the Spanish stock market (Nicolau and Sellers, 2002), and the other four studies are in the Chinese context. They investigate the reactions of the Chinese stock market to quality management (Lin and Su, 2013), product recall (Zhao *et al*., 2013), purchase and sales contract (Yang *et al*., 2014), and environmental initiatives (Lam *et al*., 2016).

An important consideration when identifying an event of interest is whether an unambiguous definition of the event could be provided. In some cases, defining the event itself or its proxy variable is a straightforward task. For example, product recalls in the U.S. are managed by five specific federal agencies and the announcement of a product recall conveys detailed information about the product being recalled, and the firm recalling it, making the identification of product recalls less subjective (Ni *et al*., 2014). However, some events have broader meanings in nature, and researchers need to define clear boundaries of the events with a set of keywords. For example, Hendricks and Singhal (2003) relied on a combination of various keywords such as delay, shortfall, shortage, manufacturing, production, shipment, delivery, parts, and components, to identify the announcements of supply chain glitches.

Another important consideration is whether the event is unexpected by the investors before being announced and whether it is visible to investors when being announced. This is because, based on the Efficient Market Hypothesis (Malkiel and Fama, 1970), the underlying assumption of all the short-term event studies, any new information available in the stock market will be reflected immediately in security price changes (MacKinlay, 1997). For example, if there is information leakage of an OSCM event such as a product recall, the firm's stock price will be affected before the official announcement, and the market reaction captured on the event day may just be a residual adjustment of the real expectations.

2.4.2 Event window

The event window is the time period over which the effect of an event will be examined. An event window is denoted as (*-x, +y*). The announcement date of an event is usually set as day 0. It is also possible that the announcement is made public after the stock market is closed, then day 0 is adjusted as the next trading day after the announcement date. The event window (*-x, +y*) includes *x* trading days before day 0 to capture any information leakage, and *y* trading days after day 0 to account for any delay of the market in perceiving the information.

Table 2.4 Summary of tests for significance of abnormal returns

Parametric test	Studies	Sample size	Estimation windows (day)	Event windows (day)	Model for estimation	Nonparametric test
Panel A: Traditional t-test						
t test	Ba *et al*. (2013)	261	(-259, -10)	(-1, +1)	Market Model	Wilcoxon signed-rank test, binomial sign test
	Jacobs *et al*. (2010)	780	(-210, -11)	(-1, 0)	Market model	Wilcoxon signed-rank test, binomial sign test
	Jacobs (2014)	450	(-210, -11)	(-1, 0)	Market Model	Wilcoxon signed-rank test, binomial sign test
	Hendricks and Singhal (2003)	519	(-210, -11)	(-1, 0)	Market model, market adjusted model, mean adjusted model	Wilcoxon signed-rank test, binomial sign test
	Hendricks and Singhal (1997)	101	(-210, -11)	(-1, 0)	Market model	N.A.
	Hendricks *et al*. (1995)	128	(-214, -15)	(-1, +1)	Market model	N.A.
	Hendricks *et al*. (2009)	307	200-day	(-1, 0)	Market model	N.A.
	Jacobs and Singhal (2014)	165	(-210, -11)	(-1, 0)	Market Model	Wilcoxon signed-rank test, binomial sign test
	Klassen and McLaughlin (1996)	162	(-209, -10)	(-1, +1)	Market model	Wilcoxon signed-rank test, binomial sign test
	Lam *et al*. (2016)	556	200-day	(-1, +1)	Market model	Wilcoxon signed-rank test
	Lin and Su (2013)	20	(-210, -11)	(-1, +10)	Market model, market adjusted model, mean adjusted model	Wilcoxon signed-rank test, binomial sign test
	McGuire and Dilts (2008)	204	(-210, -11)	(-1, +1)	Market model, market adjusted model, mean adjusted model	Wilcoxon signed-rank test, binomial sign test
	Paulraj and Jong (2011)	140	(-261, -10)	(-1, +1)	Market model, mean adjusted model, market adjusted model	Wilcoxon signed test, generalized sign test, rank test
	Xia *et al*. (2016)	264	(-220,-21)	(-1, 0)	Market model	Wilcoxon signed-rank test, binomial sign test
	Yang *et al*. (2014)	318	N.A.	2-day	N.A.	N.A.
z test	Dam and Petkova (2014)	66	(-110, -11)	0	Market model	N.A.

Parametric test	Studies	Sample size	Estimation windows (day)	Event windows (day)	Model for estimation	Nonparametric test
Panel B: Modifications to the traditional t-test						
Brown and Warner (1985) t-test	Hendricks and Singhal (1996)	91	(-210, -11)	0	Market model, market adjusted model, mean adjusted model	Wilcoxon signed-rank test, binomial sign test
	Mitra and Singhal (2008)	144	200-day	(-1, 0)	Market model, mean adjusted model	Wilcoxon signed-rank test, binomial sign test
	Jacobs and Singhal (2017)	39	200-day	(0, +10)	Market model	Wilcoxon signed-rank test, binomial sign test
Time-series standard deviation test, portfolio *t*-test	Modi *et al*. (2015)	146	255-day	(-1, +1), (-2, +2)	Fama-French four-factor model	Generalized sign test, Wilcoxon signed rank test
Jaffe test	Nicolau and Sellers (2002)	27	147-day	(-3, +3)	Market model	Corrado rank test
Patell *Z* test	Zhao *et al*. (2013)	42	(-130, -11)	(0, +1), (-5, +1)	Market model	Wilcoxon signed-rank test, binomial sign test
t-test, Patell *Z*-test, standardized cross-sectional *t*-test	Ni *et al*. (2014)	164	(-270, -21)	(-1, 0)	Market model, market adjusted model, mean adjusted model, size-and-industry adjusted model	Wilcoxon-Mann-Whitney test
Cross-sectional standard deviation test, standardized Patell *Z* test, crude dependence adjustment test	Girotra *et al*. (2007)	132	(-255, -10)	(-2, +4), (-3, +3), (-4, +4)	Comparison period model, market model, Fama-French three-factor model	Generalized sign-z test, Wilcoxon signed rank test
Cross-sectional *t*-test, Patell *Z* test, BMP *t*-test	Wood *et al*. (2017)	135	(-131, -11)	(0, 1)	Market model	Wilcoxon signed ranks test, sign test
Cross-sectional variance-adjusted Patell test	Kalaignanam *et al*. (2013)	158	(-260, -30)	(0, +1), (0, +2), (-2, 0), (-1, +2), (-2, +1), (-2, +2)	Fama-French four-factor model	N.A.
Heteroscedasticity consistent standard errors *t*-test	Sabherwal and Sabherwal (2005)	89	(-300, -46)	(-2, +2), (-3, +3)	Market model	N.A.
Patell test	Thirumalai and Sinha (2011)	223	120-day	(0, +1), (-1, 0), (-1, +1), (-5, +5), (-10, +1), (-10, +10)	Market model	Binomial sign test
Patell test, standardized cross-sectional test	Brandon-Jones *et al*. (2017)	37	(-210, -11)	0	Market model, market adjusted model, mean adjusted model	Rank test, generalized sign test

It is customary to expand the event window to several days around the event day. As shown in Table 2.4, 83% (24 articles) of the short-term event studies in OSCM adopt the standard event windows including day -1, day 0, and day 1, or some combinations of them. However, the event window could also be expanded longer if there are theoretical reasons to justify for the leakage or dissipation of information over a relatively long period (MacKinlay, 1997). In practice, it is a standard procedure to use alternative event windows for the robustness test. For example, Thirumalai and Sinha (2011) used various event windows including (-1, 0), (-1, +1), (-5, +1), (-5, +5), (-10, +1), and (-10, +10) to assess the sensitivity of their results.

The event windows do not typically overlap across different securities. The absence of overlap implies that the abnormal returns are independent across securities, satisfying the assumption for the subsequent significance tests. However, sometimes event window clustering is inevitable. For example, in the case of a single event such as a natural disaster, release of policy or other macroeconomic events, the event days are the same across the firms. A single event day would lead to considerable correlations of the abnormal returns among securities. In order to address the issue of cross-sectional correlation, several modifications of the traditional significance tests need be adopted, which I will discuss in Section 2.5.

2.4.3 Collect data

The process of collecting a representative sample of event announcements may not be necessary for external events such as the change of government policies and the occurrence of natural disasters, as these events could affect all firms in specific industries or geographic locations (e.g., Desai *et al*., 2007). However, for internal events, the process is important and can be further divided into three steps as follows:

(1) select suitable data sources, (2) compile a set of keywords and set the time period during which the announcements will be collected, and (3) eliminate the confounding announcements.

Proper data sources have a good coverage of timely press releases and reach the major investors. Table 2.3 shows that most OSCM event studies collect announcements from two databases, namely Dow Jones Factiva and LexisNexis (e.g., Ba *et al*., 2013; Hendricks and Singhal, 2003; McGuire and Dilts, 2008; Sabherwal and Sabherwal, 2005; Xia *et al*., 2016). These two databases aggregate global information from major newswires including Public Relations (PR) Newswire, Business Wire, Dow Jones Newswires, Reuters News, *The New York Times*, *The Wall Street Journal*, and other news sources. While Dow Jones Factiva and LexisNexis are widely used, other databases with specialties are adopted in country-specific studies outside the U.S. and industry-specific studies. For example, in a study of quality management based in the Spanish market, Nicolau and Sellers (2002) collected announcements from the database Baratz, which contains information of news published in important Spanish newspapers. Studies in the Chinese context use databases such as China Infobank (Zhao *et al*., 2013) and WiseNews (Lam *et al*., 2016) that cover the major Chinese security newspapers, including *Shanghai Securities News*, *Securities Daily*, and *Secutimes*. In terms of industry-specific research, additional databases gathering industry information are often used as complementary. For example, studying product recalls in the Chinese automobile industry, Zhao *et al*. (2013) used the Chinese Automobile Recall Website, in addition to China Infobank. Girotra *et al*. (2007) searched the R&D Insight database developed by Australasian Drug Information Service (ADIS) international to probe into the pharmaceutical industry. In addition to conducting a primary search in multiple databases, a rigorous search process also includes a second search in other databases with wider coverage to address potential information leakage. For example, Modi *et al*. (2015) double checked Factiva to identify earlier announcements. If multiple announcements regarding the same event are identified, the announcement with the earliest date should be collected.

The selection of keywords and time period used in the searching process can be regarded as a tradeoff and usually requires multiple revisions. On the one hand, the searching process should generate a sufficient sample for statistical analysis. On the other hand, the set of keywords and time period should be conservative to ensure the definition of the event is explicit and consistent over time. In practice, keyword selection is a retrospective process. The primary search usually starts with a small set of keywords. A limited number of announcements well-fitting the boundaries of the event definition are collected. Then researchers read these announcements to identify additional phrases commonly used in the media. Finally, all the keywords identified will be included in searching for the announcements. As seen in Table 2.3, announcements are collected over time periods ranging from two to 38 years. The lengths of the time periods vary according to different event types. For some events occurring less frequently such as product recalls in the toy industry (Wood *et al*., 2017), announcements are collected over a longer time period. In spite of the wide range of time periods, most studies set their time periods around ten years. An extremely long time period could be problematic in some cases. For example, information technology adoption and international standards could have different definitions over time. Inconsistent definition of the event could generate biased results. For example, Lo *et al*.

(2009) indicated that ISO 9000 underwent a major revision in 2000 with a change in emphasis, and a time-based investigation of ISO 9000 adoption is necessary.

The last step is to eliminate the confounding announcements. Confounding announcements are made by the same entity on dates around the event date. If not eliminated, other events rather than the event of interest may contaminate the measurement of the abnormal returns and decrease the internal validity, especially in short-term event studies. As in short-term event windows, the distribution of the abnormal returns due to the confounding announcements may not have a mean of zero (Sorescu *et al*., 2017). My survey of the literature shows that OSCM researchers do not appear to have been sensitive to this issue. About 45% of the studies do not clearly state that they have eliminated the confounding announcements, as shown in Table 2.3. Among those studies eliminating the confounding announcements, practices vary across different studies due to a lack of strict guidance as to what type of announcements should be concerned about. For instance, Modi *et al*. (2015) only considered the announcements of earnings release, merger and acquisition, change of a CEO or CFO, debt restructuring, and an unexpected dividend change. Brandon-Jones *et al*. (2017) considered a wider range of information including all the announcements within the same event window.

2.4.4 Predict normal returns

In event studies, the effect of a specific event is measured by the stock market reaction, which is computed as the difference between actual and expected stock returns. As only the actual stock returns after the event can be observed, the stock returns in the absence of the event can only be estimated. Table 2.4 indicates that the most popular estimation model adopted in the literature is the market model (26 articles, 90%). Other statistical models adopted include the mean adjust model, market adjusted model, and Fama-French factor model.

The mean adjust model calculates the average return over the estimation window as the expected return for a specific security. Similarly, the market adjusted model uses the returns of the market portfolio return $R_{m,t}$ over the event period as the estimated normal return. The market model and Fama-French factor model are more sophisticated, which I introduce as follows:

Market model. The market model (Scholes and Williams, 1977) assumes a linear relationship between the return of a specific security and the return of the market portfolio as follows:

$$R_{i,t} = \alpha_i + \beta_i R_{m,t} + \varepsilon_{i,t} \text{ with}$$

$$E(\varepsilon_{i,t}) = 0 \text{ and } var(\varepsilon_{i,t}) = \sigma_{\varepsilon_i}{}^2,$$

where $R_{i,t}$ denotes the stock return for security i in period t, $R_{m,t}$ is the period t returns of the market portfolio, $\varepsilon_{i,t}$ is the zero mean disturbance term, and α_i and β_i are estimated for each security over the estimation window.

Fama-French four-factor model. The Fama-French four-factor model is an extension of the three-factor model (Fama and French, 1993) by adding a moment factor (MOM) (Carhart, 1997) as follows:

$$R_{i,t} - R_{f,t} = a_i + \beta_i(R_{m,t} - R_{f,t}) + s_i SMB_t + h_i HML_t + m_i MOM_t + \varepsilon_{i,t} \text{ with}$$

$$E(\varepsilon_{i,t}) = 0 \text{ and } var(\varepsilon_{i,t}) = \sigma_{\varepsilon_i}{}^2,$$

where $R_{i,t}$ denotes the stock return for security i in period t, $R_{m,t}$ is the period t returns of the market portfolio, $R_{f,t}$ is the period t risk-free return rate, SMB_t is the return on a diversified portfolio of small stocks minus the return on a diversified portfolio of big stocks, HML_t is the difference between the returns on the diversified portfolios of high and low stocks, MOM_t is the difference between the portfolios of high prior return stocks and low prior returns, lagged one month, and $\varepsilon_{i,t}$ is the zero-mean residual.

The assumptions of these statistical models are that the stock returns are jointly normal, and independently and identically distributed through time. MacKinlay (1997) noted that although the assumptions are strong, they are empirically reasonable and the references using these models are robust to deviations from the assumptions. Therefore, ordinary least square (OLS) regression is often used for estimation.

Once the estimation model is chosen, the parameters in the factor models are estimated over the estimation window. As shown in Table 2.4, the estimation windows in the literature range from 120 days to 255 days. The estimation windows are usually long in order to address the bias in abnormal returns due to out-of-sample estimation. In addition, the estimation window typically does not overlap with the event window. Table 2.4 shows that the estimation window ends at least ten days prior to the event day. Avoiding overlap prevents the normal returns used to estimate the model parameters being influenced by the event. After the model parameters are estimated, the expected normal returns $\widehat{R_{i,t}}$ can be calculated over the event window.

2.4.5 Test abnormal returns

The abnormal return is calculated as a firm's actual *ex post* return minus its expected normal return over the event window. For firm *i* and event day *t*, the abnormal return is

$$AR_{i,t}=R_{i,t}-E(R_{i,t}),$$

where $AR_{i,t}$, $R_{i,t}$, and $E(R_{i,t})$ are the abnormal, actual, and expected returns, respectively. Then the abnormal returns are aggregated through the event window and across securities to capture the overall effect of the event as follows:

$$\overline{CAR}(t_1, t_2) = \frac{1}{N} \sum_{i=1}^{N} CAR_i (t_1, t_2),$$

where $\overline{CAR}(t_1, t_2)$ is the average cumulative abnormal returns over the event window (t_1, t_2) for all the securities i , $i = 1, \ldots, N$.

An important assumption for aggregation is that there is no clustering of the event windows among the securities, so $CAR_i(t_1, t_2)$ is assumed to be independent across the securities. The assumption of independence simplifies the calculation of the variance of $\overline{CAR}(t_1, t_2)$, as the covariance across the securities will be zero. In addition, the abnormal return is actually the disturbance term of the estimation model calculated on an out-of-sample bias. The additional variance due to the sampling error approaches zero after divided by the long estimation window. So the conditional variance of abnormal returns can be estimated as the disturbance variance $\sigma_{\varepsilon_i}{}^2$ in the estimation period.

Under the null hypothesis that the event has no impact on the stock returns, the cumulative abnormal return follows the distribution as follows:

$$\overline{CAR}(t_1, t_2) \sim N[0, var(\overline{CAR}(t_1, t_2))],$$

where

$$var(\overline{CAR}(t_1, t_2)) = \frac{1}{N^2} \sum_{i=1}^{N} (t_2 - t_1 + 1) \sigma_{\varepsilon_i}{}^2.$$

The null hypothesis that the cumulative abnormal return is zero can be tested using

$$\theta = \frac{\overline{CAR}(t_1,t_2)}{var(\overline{CAR}(t_1,t_2))^{1/2}} \sim N(0, 1).$$

The parametric *t*-test above is the traditional approach to assess the significance of the cumulative abnormal returns and has been used in many of the OSCM event studies (55%) (e.g., Hendricks and Singhal, 1997; Jacobs, 2014; Lin and Su, 2013; McGuire and Dilts, 2008). This approach, though simple, relies on relatively strong assumptions of independence and homoscedasticity among the abnormal returns. However, in practice, the assumptions sometimes can be violated in circumstances of clustering of the event days and event-induced volatility. Table 2.4 presents the traditional approach and the modifications adopted by OSCM researchers. The most commonly adopted modifications are the crude dependence adjustment test (Brown and Warner, 1985), standardized residual test (Patell, 1976), and standardized cross-sectional test (Boehmer *et al*., 1991). In addition to parametric tests, researchers also conduct non-parametric tests such as the Wilcoxon signed-rank test and binomial sign test to address the concern of skewness in the distribution of the abnormal returns (Hendricks and Singhal, 1996; Lam *et al*., 2016).

2.4.6 Cross-sectional analysis

Event study is powerful as it links the new information about an event of interest and stock prices by isolating the component of price changes due to the firm-specific event from other factors such as market-wide movements. Generally, significant positive abnormal returns indicate increased future performance expected by investors due to a specific event, and vice versa. As indicated in my survey, the market reaction to the same type of event varies in different contexts. For instance, while some studies show that product recalls have a negative impact on the financial performance of both manufacturers and retailers (Ni *et al*., 2014; Wood *et al*., 2017; Zhao *et al*., 2013), Thirumalai and Sinha (2011) found that firms in the medical device industry are not significantly affected by product recalls. Mixed results in the literature indicate that it would be informative to further investigate the patterns or determinants of variations in abnormal returns. However, the event study is limited in explaining the mechanisms of how the effect will vary across firms. Therefore, researchers of OSCM event studies often conduct cross-sectional regression and ANOVA to provide further insights (23 articles, 80%).

Cross-sectional regression is conducted to identify the determinants of variations in abnormal returns. The dependent variable is the cumulative abnormal return for each security over the event window, and the independent variables usually include the moderating variables specific to each research context. For instance, Kalaignanam *et al*. (2013) found that, in Customer Relationship Management (CRM) outsourcing, capabilities of the outsourcing firms, distance between the outsourcing firm and the vendor, and the type of CRM process being outsourced moderate the shareholder value of CRM outsourcing. Jacobs (2014) showed that the market reaction to voluntary emission reduction is associated with the time, emissions type, and whether the reduction is announced *ex ante* or *ex post*.

In addition to the moderating variables unique to each research context, it is also important to include firm-level, industry-level, and macro-level control variables to account for the influences of other factors on the stock returns. In line with the finance literature, most OSCM event studies adopt firm-level variables such as firm size, financial leverage, and book-to-market ratio; industry-level variables such as industry dummy variables and industry competition; and macro-level variables including recession dummy variables and time trend.

ANOVA is adopted to separate the mixed effects among different subgroups from the overall effect (Paulraj and Jong, 2011; Zhao *et al*., 2013). In essence, ANOVA is equivalent to linear regression in terms of the estimation model, whereas they have different concentrations. Linear regression is mostly concerned about identifying variables that either mitigate or magnify the abnormal returns, while ANOVA concentrates on discerning the mixed effects between subgroups with different characteristics.

2.5 Recommendations for future short-term event studies in OSCM

The systematic review of the practices in conducting short-term event studies in OSCM allows us to uncover several methodological issues that need further attention. I identify several research design issues regarding event identification, event window selection, confounding effect, self-selection bias, estimation model, significance test, and time and industry clustering, and suggest ways to address them, thus providing OSCM researchers with practical recommendations for conducting future short-term event studies.

2.5.1 External events and non-U.S. context

My analysis of short-term event studies in OSCM indicates that most researchers focus on internal corporate events in the U.S. context, while less is known about the effects of external events and in the non-U.S. context. While it seems to be the same case as in other areas such as marketing (Sorescu *et al*., 2017), I believe OSCM researchers should pay special attention to such research opportunities due to the emergence of the global supply chain. In particular, firms are more closely related than ever and can hardly be isolated from the risks originating from external supply chain partners or catastrophic disasters across national borders. In addition, non-U.S. countries, especially developing countries, have been playing the prominent role of being sourcing destinations in global supply chains. Validating findings from previous studies across different countries is important in advancing our understanding of the global value of OSCM events.

First, while it is intuitively compelling that supply chain disruptions have negative impacts within a specific company, it remains unsettled as to the transmission effects on external parties. Negative or positive transmission effects have been documented for firms having cooperative or competitive supply chain relationships with initially-disrupted firms (Barrot and Sauvagnat, 2016; Erwin and Miller, 1998; Ferstl *et al.*, 2012). In my survey of short-term event studies in OSCM, only one study conducted by Jacobs and Singhal (2017) documents the shareholder value effect of external events in terms of the Rana Plaza disaster in Bangladesh.

Second, despite the important role of developing countries in global supply chains, event studies in developing countries are far from adequate. Event studies in developing countries complement the existing knowledge in developed countries. The same type of events could have different or even opposite effects in the context of developed and developing countries having different cultural, political, and institutional environments. For example, Lam *et al*. (2016) found that in contrast to the Western context, Chinese investors react negatively to corporate environmental initiatives in China. They believe that the difference could be explained by Chinese investors' risk-taking investment strategy and China's fluctuating environmental policies and regulations.

One challenge of conducting event studies regarding external events is the concern about cross-sectional correlation in the significance test for abnormal returns. As previously argued, an important assumption for the traditional significance test of cumulative abnormal returns is independence among the securities. This assumption requires that the event days do not overlap and the correlation among the securities is assumed to be zero. Otherwise, in the case of total clustering, meaning the event days for all the securities are the same, the under-estimated covariance between abnormal returns will lead to a substantial over-rejection problem (MacKinlay, 1997; Kolari and Pynnönen, 2010). In event studies of internal activities, the event announcements are checked before analysis to ensure that there is no overlapping of the event windows. However, in event studies of external events, especially in the cases of policy change, industrial regulations, catastrophic disasters, and wars, the event days are the same. I suggest that researchers studying external events modify the traditional significance test to correct the problem of cross-sectional correlation. Two common modifications are the test using time-series mean abnormal returns (Brown and Warner, 1985) and the test using calendar-time abnormal returns (Jaffe, 1974). Jacobs and Singhal (2017) tested the time-series mean abnormal returns in their study of Bangladesh collapse to address the problem of correlation resulting from the same event day.

The other challenge arising from the non-U.S. context is the concern of market efficiency in emerging markets. The fundamental assumption of conducting short-term event studies is Efficient Market Hypothesis, a violation of which may lead to unconvincing conclusions. Some event studies in finance also cast doubt on the efficiency of emerging markets with empirical evidence. For instance, based on a study of Mexican Stock Exchange, Bhattacharya *et al*. (2000) found that firms' stock prices are not sensitive to a variety of corporate news announcements, as the unrestricted insider trading causes the stock prices to fully incorporate the superior information before public announcements. Moreover, Bekaert and Harvey (2002) pointed out that emerging markets are typically characterized as thin markets, where infrequent trading and slow adjustment to information may result in high serial correlation in daily returns. In addition, Chinese stock market was not completely open until the non-tradable shares (NTS) reform initiated in 2005 (Liu and Tian, 2012). Before the NTS reform, holders of non-tradable shares had almost the same rights as holders of tradable shares, except for public trading. Therefore, OSCM researchers who are interested in conducting short-term event studies in emerging markets should pay close attention to the issue of market efficiency and perform additional tests (e.g., alternative event windows, adjusted significance tests) to verify the robustness of their findings. For instance, in addition to the three-day event window, Lam *et al*. (2016) recalculated the abnormal stock returns over longer event windows ranging from 5 to 21 days to verify their findings regarding Chinese investors' reactions to corporate environmental initiatives. On the other hand, in order to address the concern of serial correlation resulted from non-synchronous trading, Chen *et al*. (2009) adopted the cross-sectional test and standardized cross-sectional test (Boehmer *et al*., 1991) to address the concern of serial correlation in the Chinese stock market. Moreover, in an investigation of environmental incidents in the Chinese context, Lo *et al*. (2017) excluded the announcements made in or before 2005 in consideration of potential violation of the Efficient Market Hypothesis due to non-tradable shares.

2.5.2 Justify the event window

Although there is no universal rule on the lengths of the event windows, the survey of short-term event studies shows that the event windows are usually short. About 83% (24 articles) of the studies set the event window as combinations of -1, 0, +1 days. Short event windows are recommended not only based on the Efficient Market Hypothesis, but also due to the costs of expanding them. According to the Efficient Market Hypothesis, the stock market reacts almost immediately to any new information available. Therefore, without theoretical justifications for information leakage or slow dissipation, including one pre-event day and one post-event day should be sufficient to account for possible information leakage, as well as the market reaction after the stock market is closed. Moreover, expanding the event windows leads to decreased sample size and reduced power of analysis (Brown and Warner, 1985). As discussed previously, preliminary sample announcements need to be checked to remove confounding events and overlapping event windows. Longer event windows are more likely to be affected by confounding events, as well as overlapping with the event windows of other firms. Decreasing the sample size can be costly, especially when the preliminary sample size is already small. In addition, the power of analysis will be substantially decreased. Brown and Warner (1985) compared the power of analysis when the abnormal returns are measured over the event windows of 0 and (-5, +5). They found that with an actual level of 1% abnormal performance, the rejection frequency for market adjusted returns is only 13.2% in the 11-day event window, compared with 79.6% in the one-day event window.

However, with theoretical justifications, event windows can be expanded according to the nature of the event. One example is the event window of (0, +11) in a study of a catastrophic disaster (Jacobs and Singhal, 2017). The authors argued that a disaster such as the collapse of a garment factory is unexpected and unintended, so there is no evidence of information leakage. Besides, the information about the severity of the disaster may be gradually revealed, so it is reasonable to include longer post-event days. Unfortunately, the survey shows that two of the five event studies with longer event windows do not provide clear justifications (i.e., Lin and Su, 2013; Nicolau and Sellers, 2002).

2.5.3 Confounding announcements

The isolation of the confounding effect of other financially related events is perhaps one of the most critical assumptions of the short-term event study method (McWilliams and Siegel, 1997). McWilliams and Siegel (1997) demonstrated the importance of controlling confounding announcements by replicating three event studies of corporate social responsibility published in *Academy of Management Journal.* They found that after controlling the confounding effect, the significant abnormal returns reported in the three event studies all became insignificant.

However, the survey shows that efforts should be made to strengthen the awareness of controlling confounding announcements among OSCM researchers. In particular, in addition to emphasizing the necessity of controlling confounding effect, more discussion is needed about the execution of identifying confounding announcements, as there is no strict guidance in the literature as to what announcements should be controlled. Table 2.3 shows that some researchers examined the sample announcements and excluded those containing both the event of interest and other material information (Hendricks and Singhal, 2003; Hendricks *et al*., 2009; Jacobs, 2014). Some other researchers considered the announcements which have been shown to significantly affect stock returns including earnings or dividends announcements, key executive appointments, merger and acquisitions, restructuring or divestiture (Klassen and McLaughlin, 1996; Lam *et al*., 2016; Modi *et al*., 2015; Nicolau and Sellers, 2002; Paulraj and Jong, 2011; Sabherwal and Sabherwal, 2005). Other researchers set a wider range and argued that any other announcements released by the sample firm around the event date may cause potential contamination (Brandon-Jones *et al*., 2017; Hendricks and Singhal, 1996; Jacobs and Singhal, 2017; Jacobs *et al*., 2010). It is noteworthy that eliminating confounding announcements with a broader definition or over a longer time period may reduce the possibility of contamination, but it could also reduce the sample size significantly. To strike a balance, I recommend researchers to at least control those common confounding announcements identified by McWilliams and Siegel (1997), such as dividend declarations, earnings announcements, key executive appointments, restructuring or divestiture, merger and acquisition, joint ventures, major litigation or labor unrest, forecasted changes in sales or earnings, and major contracts over the event window.

2.5.4 Self-selection bias

The majority of the event studies I reviewed are based on self-announced events adopted voluntarily by firms. Firms proactively initiate events such as environmental management, quality management, R&D projects, sourcing strategies rather than being passively prompted to pursue them. For instance, Ni *et al*. (2014) are interested to assess how product recalls may affect the U.S. public-listed retailers' stock returns. In the cumulative abnormal return (CAR) analysis, the effect of product recalls is quantified as the actual ex-post return minus the estimated normal return of the firms making recall announcements. However, as suggested by the authors, retailers who choose to initiate product recalls may differ from those who choose not to. Specifically, firms with better reputation are more likely to initiate product recalls. Due to the self-selection, a significant difference in mean abnormal returns could be observed between the two populations independent of the impact of product recalls. For example, firm reputation has been shown to affect consumers' reactions to product harm crisis (Siomkos and Kurzbard, 1994). Consumers felt that the products failures are less severe when sold by firms with better reputation. Therefore, the average treatment effect calculated with only the treated group (i.e., CAR for the U.S. public-listed retailers making announcements) may underestimate the average treatment effect on the population (i.e., the "true" effect on all U.S. public-listed retailers) (Austin, 2011; Heckman, 1979).

In the cross-sectional analysis, the CAR of a particular firm is usually regressed on its observable characteristics to explain the variations in the CAR. However, as CAR is only observed for a subsample of the population (i.e., the firms making announcements), there could be a problem of endogeneity if the self-selection process is omitted from the cross-sectional model. In the example I mentioned above, an unobserved factor (i.e., firm reputation) may affect a firm's decision to initiate a product recall as well as its abnormal stock return (Ni *et al*., 2014). In this case, the unobserved factor manifests in the residual of the cross-sectional model, making the residual correlated with the explanatory variables (i.e., observable characteristics such as recall size and remedy strategies) and the dependent variable (i.e., CAR). Consequently, omitting the self-selection process in the cross-sectional model potentially violates OLS' assumption of exogeneity, leading to the bias in the estimation of coefficients (Clougherty *et al*., 2016).

Researchers should address the potential sample selection bias resulting from the systematic differences between the sample and non-sample firms. My survey shows that only seven out of the 29 studies address the potential sample selection bias issue (i.e., Paulraj and Jong, 2011; Dam and Petkova, 2014; Hendricks *et al*., 2009; Jacobs, 2014; Kalaignanam *et al*., 2013; Modi *et al*., 2015; Ni *et al*., 2014).

To correct the biased estimation of treatment effect in the CAR analysis, a common practice is to mimic the random selection process. Researchers construct a benchmark group and directly compare the abnormal stock returns between the sample firms and the benchmark firms. The benchmark firms are selected from the pool of firms not involved in the events based on certain criteria. Conditional on the specific matching criteria, the distribution of observed baseline characteristics is similar between the sample firms and benchmark firms. Then the differences in abnormal stock returns during the event window are calculated and tested for significance. While the rationale to control for self-selection bias is the same, approaches to generate the benchmark group vary across different studies.

Traditionally, researchers use the one-to-portfolio or one-to-one matching approach to develop the benchmark group (e.g., Paulraj and Jong, 2011; Hendricks *et al*., 2009). Specifically, all the listed firms are assigned to portfolios based on various characteristics that are believed to influence stock returns. The characteristics frequently included in the OSCM event studies are industry, firm size, and prior firm performance. Then a group of firms or a single closest firm in the same portfolio to the sample firm is selected as the benchmark. Admittedly, it is difficult to get benchmarks that are all well matched on all the criteria and there are tradeoffs among criteria. There are also some limitations when high-dimension criteria are used because it is difficult to determine along which dimensions to match and which weighting scheme to adopt (Dehejia and Wahba, 2002).

Propensity score matching (PSM) is another approach used in the OSCM literature to construct the benchmark group (Modi *et al*., 2015). Different from the portfolio matching method, PSM reduces the dimensionality by generating a propensity score. The propensity score is the probability of treatment assignment conditional on observed baseline characteristics. It can be estimated with a probit or logit model from the observational data on treatment assignment and baseline characteristics. Based on the estimated propensity scores of all the firms, the firms in the comparison group that have the closest scores to the sample firms are identified as the benchmark.

To address the omitted variable bias in the cross-sectional analysis, an approach commonly adopted is Heckman's two-stage selection model (Dam and Petkova, 2014; Kalaignanam *et al*., 2013; Ni *et al*., 2014). Different from the two aforementioned matching methods that mimic the random selection process in the context of observational studies, this model corrects the sample selection bias by first estimating the values of the omitted variables, and then using the values as regressors in estimating the effect of the event on the stock returns (Heckman, 1979). Accordingly, Heckman's model includes two equations. In the first equation, the probability of a firm undertaking a specific event is modelled with probit analysis for the full sample. The inverse Mills ratio is generated from the first equation and represents the probability that an observation is selected to include in the sample. In the second equation, the effect of the event on abnormal returns is estimated with the OLS function. The inverse Mills ratio is added as an additional explanatory variable in the OLS function and indicates whether selection bias is an issue. One of the concerns in implementing this method is the selection of variables that may account for the selection bias.

A key challenge to implementing both PSM and Heckman's two-stage model is to determine the explanatory variables to be included in estimating the selection model. The possible sets of variables recommended in the literature include baseline variables that influence the outcome (i.e., stock returns in event studies) and baseline variables that influence the treatment assignment (i.e., the probability of occurrence of the event) (Austin, 2011; Heckman and Navarro-Lozano, 2004). In practice, the baseline variables are usually selected specific to each research context, based on theoretical justifications, and tested with difference analysis. For example, Dam and Petkova (2014) assumed that consumer pressure that differs across industries explains firms' participation in supply chain sustainability programmes. They further tested whether there are differences in firm-level characteristics that could serve as potential baseline variables. Based on the information from the two steps, they included industry dummy as the explanatory variable in the probit model. Modi *et al*. (2015) included the variables of productivity, leverage, capital resource slack, market-to-book ratio, and firm size that affect abnormal returns as the baseline variables.

2.5.5 Estimation model

The statistical asset pricing models adopted in short-term event studies in OSCM are two simple models including the mean adjusted model and market adjusted model, and two factor models including the market model and Fama-French factor model. Among the four models, the factor models are commonly adopted for major data analysis, while the other two simple models are often used in the sensitivity test. The factor models are believed to be superior to the simple models in that they account for the movement in market returns in estimating the normal returns (MacKinlay, 1997). Consequently, they will reduce the variance in the estimated returns and enhance the ability to detect abnormal returns. In recent years, a number of sophisticated statistical asset pricing models have been proposed. For example, the Fama-French three-factor model (Fama and French, 1993) extends the capital asset pricing model (CAPM) by adding the size and value factors to the market risk factor. The model is further extended by adding a momentum factor by Carhart (1997), and the profitability and investment factors by Fama and French (2016).

My survey reveals a surprising fact that despite the increased sophistication, the market model has been consistently used by most researchers for stock return estimation from the earliest study I identified (Hendricks *et al*., 1995) to the latest research (Brandon-Jones *et al*., 2017; Jacobs and Singhal, 2017; Wood *et al*., 2017). This is because the improvement is very conservative with the increase in model sophistication in short-term event studies, and more sophisticated models usually yield similar results with the market model (Brown and Warner, 1985). As the daily expected normal returns usually approach zero, the reduced variance in the expected returns is too limited compared with the much larger abnormal returns. The lack of sensitivity to the models explains the prevalence of the market model across different studies in all the time periods. Therefore, I suggest that researchers choose the factor models according to the availability of data with little preference for the more sophisticated models.

However, in some cases, employing the multi-factor model could bring substantial improvement. MacKinlay (1997) suggested that if firms share common characteristics such as coming from the same industry or concentrating in the same capitalization group, researchers should consider a more sophisticated model. Since there are no specific guidelines as to under which circumstances the more sophisticated models are necessary, I suggest that researchers, whenever possible, should estimate the expected returns using alternative models to enhance the robustness of the analysis.

2.5.6 Significance tests

The most widely adopted parametric test (16 articles, 55%) in the studies I reviewed is the classical *t*-test. As previously introduced, the test assumes that the stock returns are jointly multivariate normal, and independently and identically distributed across time and among individuals (MacKinlay, 1997). Yet, in some research settings, these statistical assumptions are likely to be violated and the inferences from the classical *t*-test tend to be problematic. Researchers have modified the test to correct for prediction errors. OSCM researchers seem to be sensitive to the issue of significance tests and the most widely adopted modifications are those developed by Patell (1976), Brown and Warner (1985), and Boehmer *et al*. (1991). Table 2.5 presents a summary of the parametric tests commonly adopted in OSCM studies with key references, strengths, weaknesses, and representative OSCM studies identified for each test.

Table 2.5 Comparison of parametric tests for significance of abnormal returns

Significance Test	Key Reference	Key Assumptions	Strength	Weakness	Representative Studies
Traditional t-test	MacKinlay (1997)	Cross-sectional independence of abnormal returns; Event-induced variance is insignificant; homoscedasticity of abnormal returns	Simplicity	Prone to cross-sectional correlation; Prone to event-induced volatility; Prone to heteroskedasticity among observations	Hendricks and Singhal (2003), Jacobs *et al*. (2010), Ba *et al*. (2013), Xia *et al*. (2016)
Crude dependence adjustment test	Brown and Warner (1985)	Homoscedasticity of abnormal returns	Allow for cross-sectional correlation	Prone to heteroskedasticity among observations, less powerful	Hendricks and Singhal. (1996), Girotra *et al*. (2007), Mitra and Singhal (2008), Jacobs and Singhal (2017)
Cross-sectional test	Penman (1982)	Cross-sectional independence of abnormal returns	Allow for event-induced volatility; Allow for serial correlation	Prone to cross-sectional correlation	Wood *et al*. (2017)
Standardized residual test	Patell (1976)	Cross-sectional independence of abnormal returns; Event-induced variance is insignificant	Allow for the heteroskedasticity among abnormal returns over the event period	Prone to cross-sectional correlation and event-induced volatility	Girotra *et al*. (2007), Thirumalai and Sinha (2011), Kalaignanam *et al*. (2013), Zhao *et al*. (2013), Ni *et al*. (2014), Wood *et al*. (2017), Brandon-Jones *et al*. (2017)
Standardized cross-sectional test	Boehmer *et al*. (1991)	Cross-sectional independence of abnormal returns	Allow for the heteroskedasticity among abnormal returns over the event period; Allow for event-induced volatility; Allow for serial correlation	Prone to cross-sectional correlation	Kalaignanam *et al*. (2013), Wood *et al*. (2017), Brandon-Jones *et al*. (2017)

Since there is no universal best significance test that is well-specified in all the circumstances, the choice of test statistic should be based on the specific research setting and statistical features of the dataset under investigation. For example, Brown and Warner (1985) suggested that the adjustment of cross-sectional dependence is only necessary in special cases of extreme cross-sectional correlation such as those when firms come from the same industry or share the same event day. I suggest that researchers of industry-specific studies or studies allowing for clustering of event days should be sensitive to the problem of cross-sectional correlation. Examples of such modifications are studies conducted by Hendricks and Singhal (1996), and Jacobs and Singhal (2017).

2.5.7 Time and industry clustering

Time and industry clustering are two critical issues which potentially cause misspecification in significance tests, but they are sometimes ignored by OSCM researchers. Time clustering could be an issue when the events occur at or near the same calendar date (Henderson, 1990). It is often observed in the event studies with a focus of external events such as regulations, legislations, policies, and disasters, where firms share common event days (Kolari and Pynnönen, 2010). For example, in an investigation of the impact of Bangladeshi garment factory collapse on apparel retailers, the event day is set as the date of the Rana Plaza disaster on April 24, 2013 (Jacobs and Singhal, 2017). When the event windows overlap or are the same, the abnormal returns of sample firms are potentially correlated, which may result in non-zero covariance among abnormal returns (MacKinlay, 1997). On the other hand, industry clustering refers to the situation when the events are concentrated in the same or a small number of industries (Henderson, 1990). For instance, Girotra *et al*. (2007) investigated the influence of phase III clinical trial failures on pharmaceutical companies. Wood *et al*. (2017) examined the effect of product recalls on toy manufacturers and retailers. In the case of industry clustering, abnormal returns of industry peers tend to contemporaneously move together as they usually share common fundamentals such as supply and demand shocks. Dyckman *et al*. (1984) found that the variance of the return residuals across securities in the same industry is significantly higher, even if their returns are sufficiently diversified over time.

Time and industry clustering may cause problems in the significance test, as the vital assumption of cross-sectional independence is likely to be violated. The first step in the significance test is to aggregate abnormal returns across securities. For the aggregation, it is assumed that there is no clustering across securities so that the covariance term can be regarded as zero (MacKinlay, 1997). However, in the case of time and industry clustering, the abnormal returns across securities are potentially correlated. Ignoring the cross-sectional correlation may cause a downward bias in the estimation of the standard deviation of abnormal returns. As a result, the null hypothesis of zero abnormal returns will be rejected too frequently. Moreover, the significance test could be further misspecified in the case of both time and industry clustering, as both problems reinforce one another (Dyckman *et al*., 1984).

To address the concern of cross-sectional correlation, various approaches have been proposed in the literature. One of the most popular approaches is the portfolio approach (Brown and Warner, 1985; Jaffe, 1974). In this approach, the significance test is performed at the portfolio level so that the cross-sectional correlation across securities in the portfolio is allowed. Specifically, the securities in a specified time period are first included into one or several portfolios. Next, the average abnormal return for the portfolio is calculated as the abnormal returns aggregated over securities in the portfolio divided by the number of the securities. With the assumption that the portfolio abnormal returns are independently, identically and normally distributed over time, Student *t*-test can be employed to test the time-series of portfolio abnormal returns. The other approach is to correct the underestimated standard deviation by taking into account a correlation factor (Kolari and Pynnönen, 2010). For example, based on the BMP test (Boehmer *et al*., 1991), Kolari and Pynnönen (2010) proposed an ADJ-BMP test which adjusts the cross-sectional correlation. In the BMP test, the abnormal returns during the event period are standardized by the estimation-period standard deviation, and then the standardized abnormal returns are divided by its contemporaneous cross-sectional standard deviation. BMP test allows serial correlation, heteroscedasticity among abnormal returns and event-induced volatility, but it is prone to cross-sectional correlation. The ADJ-BMP test modifies the cross-sectional standard deviation by adding the average of the cross-correlation of the estimation-period residuals, which accounts for the cross-sectional correlation among abnormal returns in the event period.

2.6 Conclusions and limitations

Reviewing 29 short-term event studies in OSCM published between 1995 and 2017, I observe that the short-term event studies in OSCM are on the increase and about 62% of the papers were published in the recent eight years from 2010 to 2017. As the basic steps of short-term event studies remain essentially the same, the study first outlines the basic steps as suggested by MacKinlay (1997). For each step, I then analyze the practices adopted in these OSCM papers in detail. First, I find that 28 articles (97%) focus on internal corporate events, with only one article (3%) examining an external event in terms of a catastrophic disaster. Most event studies are in the U.S. context, and only five studies (17%) are in the non-U.S. context. Second, the study demonstrates that the standard event windows (i.e., including day -1, day 0, and day 1) are widely adopted in short-term event studies. However, theoretical justifications are not provided in some event studies with longer event windows. Third, multiple data sources are often used to enhance the rigour of data collection, but elimination of confounding announcements is not implemented well. About 45% of the studies do not clearly state that they have eliminated the confounding announcements, and practices vary across different studies with confounding eliminations. Fourth, the study shows that researchers are not sensitive to the estimation model of normal returns. The market model is the most popular estimation model, which is adopted in 26 articles (90%) from 1995 to 2017. Fifth, OSCM researchers are wary of possible violations of the assumptions for the significance tests. Various modifications of the classical *t*-test are adopted according to different research contexts. Sixth, subsequent cross-sectional regression and ANOVA are usually conducted to probe into the operational determinants of variations in abnormal returns (23 articles, 80%).

Based on the above analysis, I propose several recommendations for future short-term event studies in OSCM. First, I suggest that OSCM researchers pay special attention to external events that may create transmission effects along global supply chains. In addition, researchers should be careful about expanding the event windows, and provide theoretical explanations to justify the window lengths. Third, as removing confounding effect is a critical step in conducting short-term event studies, researchers should at least control those commonly identified newsworthy confounding announcements over the event window. Fourth, self-selection bias should be tested and well controlled, especially in short-term event studies with voluntary announcements.

Fifth, employing the multi-factor model could bring substantial improvement. I recommend that researchers estimate the normal returns using alternative models to enhance the robustness of the analysis. Sixth, it is necessary to modify the significance tests according to research settings in the case of external events and industry-specific studies. Finally, I urge researchers to address the concern of cross-sectional correlation in the cases of time and industry clustering.

I acknowledge that the study is limited in terms of the scope. Not all types of event studies have been taken into account. However, considering the fact that short-term event studies are the most widely adopted in OSCM research, the summary and recommendations are valuable to shed light on this topic. Also, as this study primarily deals with the methodological issues in short-term event studies, I do not focus on the results and conclusions in specific studies. To further enhance our knowledge about event studies in OSCM, this study can be extended in two ways. First, the study provides a comprehensive but not exhaustive review of the event studies in OSCM. It is possible to review the research undertaken with other types of event study methodologies such as long-term event studies and event studies with operating performance measures. Second, it would also be informative to investigate the consequences of various OSCM events and operational variables that account for variations in abnormal returns from the theoretical perspective. Different from traditional OSCM research that only focuses on one key outcome such as speed or quality, event studies in OSCM are based on the notion of strategic OSCM aimed at yielding competitive advantage and creating superior financial performance. Event studies in OSCM usually conduct ANOVA and cross-sectional regression to explain variations in abnormal returns, which rely on various theoretical lens and frameworks.

Therefore, a future review of the diverse theoretical perspectives adopted in OSCM event studies will deepen our understanding of the financial impact of OSCM practices.

Chapter 3 Study Two: The Contagion and Competitive Effects across National Borders: Evidence from the 2016 Kumamoto Earthquakes

3.1 Literature review and hypotheses development

3.1.1 Contagion and competitive effect

A review of literature in accounting and finance reveals that firm-specific announcements could generate two possible transmission effects within the industry: contagion and competitive effect. Contagion effect occurs when outside investors make similar inferences of industry peers' profitability with the information conveyed in announcements made by other firms. On the other hand, competitive effect results from the competitive position of industry peers and refers to redistribution of wealth within the industry (Lang and Stulz, 1992). This study is different from prior event studies which examine the transmission effect of a variety of financial events such as corporate layoff (Bhabra *et al*., 2011), earnings surprises (Prokopczuk, 2010), and open market share repurchase (Erwin and Miller, 1998). The study complements the existing studies which are limited to self-initiated events, domestic context, and financial events by investigating the transmission effect of natural disasters on manufacturing sector across national borders. Specifically, in the context of natural disasters, the contagion effect could transmit through two different mechanisms: supply chain disruption and information effect. Empirical studies in supply chain management have documented that the inter-firm linkage functions as an important mechanism to spread the effect of supply chain disruptions (Acemoglu *et al*., 2012; Barrot and Sauvagnat, 2016; Boehm *et al*., 2015; Carvalho *et al*., 2016). For example, Carvalho *et al*., (2016) examine the negative impact of Japanese earthquake on direct and indirect suppliers and customers of disaster-stricken firms. Acemoglu *et al*. (2012, 2016) empirically investigate how the firm-level and industry-level shocks transcend a specific industry through the mechanism of input-output linkages in the United States. Another mechanism is information effect which does not necessarily transmit via inter-firm linkages. Information effect occurs when firm announcements convey information to outside stakeholders including investors, customers, and suppliers about the profitability of not only the announcing firms, but also all firms in the same industry (Lang and Stulz, 1992), especially sector-specific information (Prokopczuk, 2010). If negative announcements are perceived by stakeholders who have limited information of individual firms in the industry, they may be wary of other firms in the same industry because the problem could be common to all the firms in the industry. Consequently, they may reassess the other firms even though they didn't make the announcements. On the other hand, the intra-industry competitive effect occurs when the market reaction to competitors' stock price is opposite to that of the announcing firms. For example, Ferstl *et al*. (2012) focus on the nuclear disaster caused by 2011 Japanese earthquake and they documented negative market reaction among Japanese nuclear industry but positive reaction among Japanese alternative energy industry due to demand shift. Therefore, I hypothesize that the overall transmission effect could be negative or positive dependent on the dominance of contagion or competitive effect.

H1a: The earthquakes have a negative impact on Chinese semiconductor firms' stock returns.

H1b: The earthquakes have a positive impact on Chinese semiconductor firms' stock returns.

3.1.2 Contagion effect and supply chain linkages

I expect the contagion effect to be more pronounced for firms with supply chain linkages with Japanese firms. In the case of Kumamoto earthquakes, there was great media coverage of the effect of the earthquake on semiconductor factories located in Kumamoto. The aftermath includes the halt of production lines, facility damages, finished product inventories damages, employee safety issues, and recovery costs and uncertainty (Fortune, 2016; BBC News, 2016). As a result, investors may expect potential supply chain disruptions in Chinese semiconductor firms which are suppliers or customers of Japanese semiconductor firms and thus react negatively. Additionally, in the case of exogenous disasters, the contagion effect might mostly transmit through supply chain disruptions, whereas the information effect could be limited. Different from firm-initiated events, earthquakes are exogenous, irresistible and occur unexpectedly, so they have no relation with the firm's former operational performance. As a result, stakeholders might not anticipate that the Chinese semiconductor manufacturers will also be less profitable even though they are in the same industry.

H2: The impact of earthquakes is more negative for Chinese semiconductor firms having supply chain linkages with Japanese firms.

3.1.3 Competitive effect, inventory turnover, and customer concentration

I expect the competitive effect to be more pronounced for firms with higher inventory turnover and higher customer concentration. Researchers claim that efficient competitors are more likely to take advantages of the miseries experienced by the announcing firms than inefficient counterparts (Lang and Stulz, 1992; Bhabra *et al*., 2011). In accounting and finance literature, firm efficiency are indicated by leverage (debt to equity ratio) and prior operating performance (Lang and Stulz, 1992; Bhabra *et al*., 2011). In the context of my study, I use level of inventory turnover and customer concentration to measure the efficiency of Chinese semiconductor firms. Specifically, higher level of inventory turnover and customer concentration indicate higher operational efficiency in the firm. Firms with higher inventory turnover achieve greater efficiency and flexibility to avoid losses or even take benefits from the earthquakes. Chopra and Sodhi (2004) point out that holding inventory can be costly because inventory costs are incurred continually and might only be used at a slight chance. Chen *et al*. (2005) examine that reduced inventory slack in American manufacturing companies brings up their financial performances. Modi and Mishra (2011) point out that, apart from lower holding cost, high inventory turnover also reduces the risk of write-offs and increase the net cash flow in companies and thus enhance their financial performance. So I expect that firms with high inventory turnover are more efficient and flexible to benefit from the earthquakes.

H3: The impact of earthquakes is more positive for Chinese semiconductor firms with higher inventory turnover.

Firms with concentrated customers achieve increased efficiency (Ak and Patatoukas, 2016; Cen *et al*., 2015; Patatoukas, 2011) and reduced operating risks (Itzkowitz, 2013; Peck and Christopher, 2003; Kleindorfer and Saad, 2005). First, firms with limited number of major customers tend to experience increased information sharing and improved production coordination and thus efficiency is gained. For example, Ak and Patatoukas (2016) show that the relationship with concentrated major customers enables the collaborative planning, forecasting, and replenishment (CPFR) and JIT adoption and thus reduces inventory levels. More empirical evidences are provided by Patatoukas (2011) who documented a net positive relationship of customer-base concentration and firm performance. He argued that the efficiency gained from less selling, general and administrative (SG&A) costs, less inventory holding, higher asset turnover rates and shorter cash conversion cycles dominates in spite of lower gross margins. Second, operating risks could be mitigated with additional cash and well-established cooperation. Itzkowitz (2013) argues that suppliers with concentrated customer base hold additional cash as a precaution against the loss of customers. Moreover, enhanced cooperation in this relationship help to improve supply chain visibility, identify vulnerabilities, and prepare joint business continuity plans (Peck and Christopher, 2003; Kleindorfer and Saad, 2005). Figure 3.1 shows the conceptual framework of this study.

H4: The impact of earthquakes is more positive for Chinese semiconductor firms with higher customer concentration.

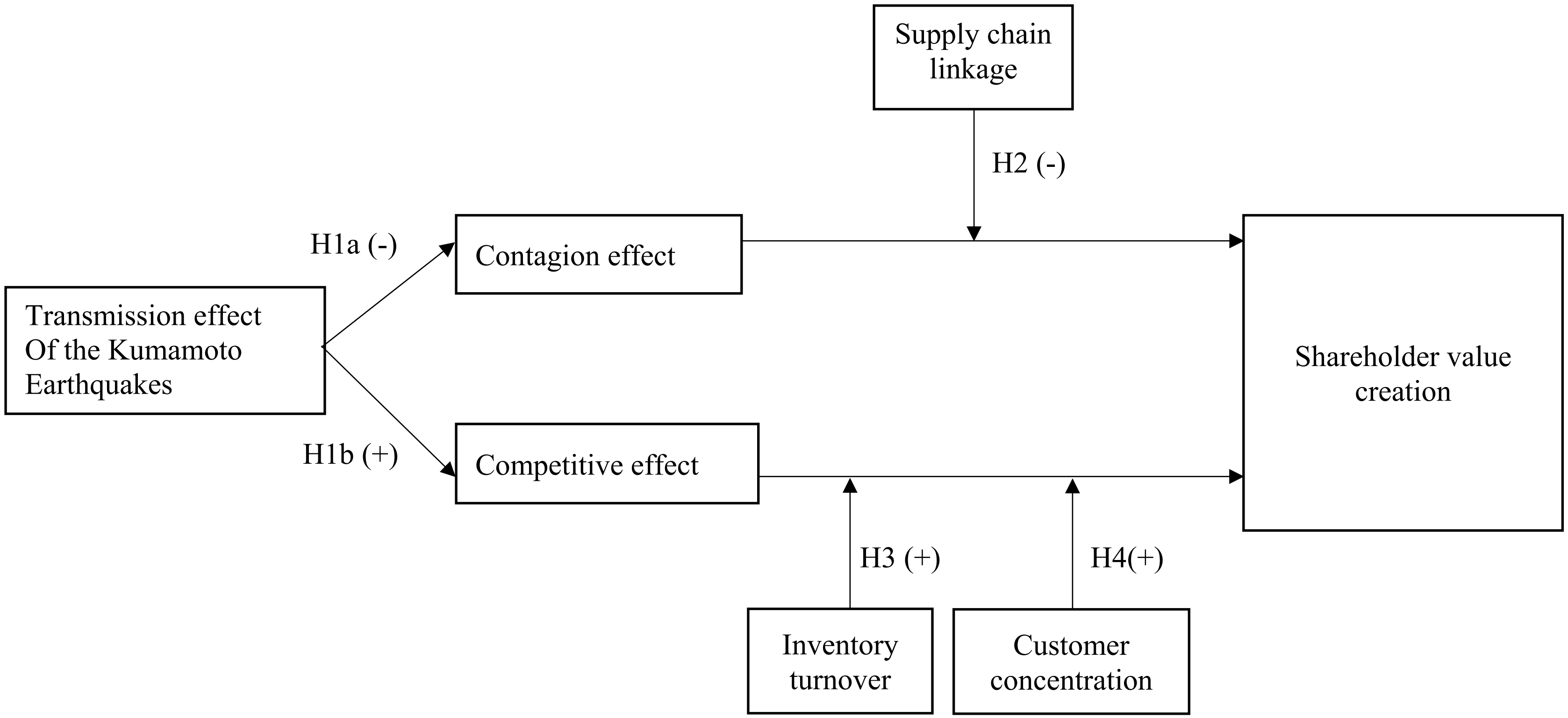

Figure 3.1 Conceptual framework

3.2 Methodology

3.2.1 Data

Since I focus on the industry-wide transmission effect rather than inter-firm propagation, different from most of the previous studies identifying sample through announcements, I construct the sample as all 170 firms listed in the Shanghai and Shenzhen Stock Exchanges and are in the Electronic parts and components sector according to the China International Trust Investment Corporation (CITIC) securities industrial classification.

For those 170 firms, I first obtain firm-level daily stock returns and accounting data from the China Stock Market and Accounting Research (CSMAR) database. CSMAR consists of several databases such as China stock market trading database and China listed firms annual report database that have been widely adopted in Chinese economic research (Gul *et al*., 2010; Liao *et al*., 2014). As shown in Table 3.1, I obtain firm characteristics data including inventory, cost of goods sold (COGS), book-to-market ratio, total debt, shareholder's equity, sales, and ownership from the China listed firms annual report database. All those data were collected in the fiscal year prior to the earthquake. In addition, CSMAR also provides the Fama-French Factors for Chinese stock markets which is developed with reference to French and Fama's papers in 1993 and 2015. I rely on the Fama-French Factors provided by CSMAR for the stock return estimation, as discussed below.

Second, I obtained supply chain linkage data from the Bloomberg database. It is difficult to measure supply chain linkage of Chinese listed firms due to the lack of relationship disclosure regulations in China. I overcame this difficulty by quantifying supply chain linkage based on the actual business relationships between firms as shown in the Bloomberg database. This database uncovers money flows between firms on both a customer (revenue) and supplier (cost) basis. It calculates the percentage of revenues a supplier received from its major customers and the percentage of COGS a customer spent on its major suppliers. This database has been used by researchers to measure supplier concentration (Steven *et al*., 2014). Similarly, I manually obtained the count of the sample firms' Japanese supplier or customer or peer companies and collected the percentage of revenues a supplier received from its major customers to measure supply chain linkage and customer concentration, respectively.

3.2.2 Short-term event study

The research adopts the short-term event study method to examine the transmission effect (i.e. negative contagion effect and positive competitive effect) of the 2016 Kumamoto earthquake on the financial performance of Chinese semiconductor firms. Short-term event study is commonly adopted to investigate the contagion effect and competitive effect of financial events (Erwin and Miller, 1998; Lang and Stulz, 1992; Prokopczuk, 2010). In recent years, the event study method has been expanded to broader research fields including supply chain risk management to study the impact of catastrophic disasters such as natural disasters, industrial accidents and so on (Brounen and Derwall, 2010; Ferstl *et al*., 2012; Jacobs and Singhal, 2017).

An advantage of adopting event study methodology in the research comes from the reduction of self-selection bias. To illustrate, past studies adopting the event study methodology to investigate firms' initiatives might have to deal with self-selection bias as those firms choose to implement the corresponding initiatives. In other words, the sample is non-random. However, since the event in my research is a natural disaster which occurs without any anticipation and intentions, the self-selection bias is unlikely to be a concern.

First, I choose a five-day event window from day 0 to day 4. I set April 14th, 2016 on which the earthquake occurred as day 0 and include four trading days after day 0 to construct the event window. I exclude pre-event days (i.e., before day 0) but include post-event days (i.e., after day 0) in the event window for the following reasons. First, earthquake occurs without any anticipation and intention and thus there is no information leakage before the event. So it is unnecessary to include pre-event days in the event window (Ferstl *et al*., 2012). On the other hand, I include post-event days because the aftermath of natural disasters like earthquakes is not revealed immediately. Information about the severity and affected area of an earthquake might be gradually unfolded over a number of days. In this case, there was a 7.0 magnitude aftershock on April 16th (day 2) and the news significantly increased after day 2. In order to account for the on-going information release, I set the event window as (0, 4). I also check the sensitivity of the results by using longer event windows including (0, 5), (0, 10), and (0, 15). I use a 140-day estimation window from day -160 to day -21. I separate the estimation window from the event window by 20 days to prevent the influence of event returns on normal return measure. In order to be included in the sample, the firms need to have market returns on both the estimation window (-160, -21) and event window (0, 4). After the elimination of 25 firms with incomplete data, I further exclude another 11 firms due to other announcements in the event window of (0, 4) to address the issue of compounding effect. In the last, I arrive at a sample of 134 firms to test the overall effect.

Second, I measure the abnormal return as a firm's actual *ex post* return minus its normal return over the event window. To estimate the normal return, I use Fama-French Five-Factor Model (Fama and French, 2015). Fama-French Five-Factor Model adds profitability (RMW) and investment (CMA) factors to the three factor model (Fama and French, 1993). Five-Factor Model shrinks anomaly average returns which are not explained in Three-Factor Model.

$$R_{it} - R_{ft} = \alpha_i + \beta_i(R_{mt} - R_{ft}) + s_i SMB_t + h_i HML_t + r_i RMW_t + c_i CMA_t + \varepsilon_{it}$$

where R_{it} is the portfolio's expected rate of return, R_{ft} is the risk-free return rate, and R_{mt} is the return of the market portfolio. SMB_t is the return on a diversified portfolio of small stocks minus the return on a diversified portfolio of big stocks, HML_t is the difference between the returns on diversified portfolios of high and low stocks. RMW_t is the difference between the returns on diversified portfolios of stocks with robust and weak profitability, and CMA_t is the difference between the returns on diversified portfolios of low and high investment stocks, which I call conservative and aggressive. ε_{it} is a zero-mean residual. The data of all the five factors come from CSMAR. Specifically, R_{mt} is the return of the market portfolio of A share and Growth Enterprise Market (GEM) on day t, R_{ft} is three-month deposit rate in China. After estimating the six coefficients in Five-Factor Model over the estimation window, I can calculate the expected normal returns and thus the abnormal returns in the event window.

Third, the aggregations of abnormal returns along two dimensions (through time and across securities) are usually calculated to capture an overall effect of the event.

However, the analysis of aggregating abnormal return assumes that firms' event windows do not overlap in the calendar time (MacKinlay, 1997). This case is different in that the event day is the same for all firms and covariance across firms will no longer be zero. Ignoring the correlations in the analysis may introduce considerable downward bias in the standard deviation which will thereby overestimate the t-statistic. Therefore, the null hypothesis will be over rejected (Kothari and Warner, 2007). To address the issue of cross-sectional correlation, I utilize the portfolio approach (Brown and Warner, 1985) which is adopted in the studies of single event (Jacobs and Singhal, 2017). The abnormal returns of all firms are aggregated into one portfolio so that the correlations across them are allowed.

3.2.3 Cross-sectional analysis

To address the second research question of how the transmission effect might vary across different firm characteristics, I divide the full sample based on the firm-level characteristics of customer concentration and inventory turnover, and use analysis of variance (ANOVA) to compare the abnormal returns between different subgroups. With reference to the measurements developed in literature (Hendricks and Singhal, 2009; Hendricks *et al*., 2009; Patatoukas, 2011; Wagner and Bode, 2006), I measure the inventory turnover and customer concentration as follows: Inventory turnover is measured as the cost of goods sold (COGS) divided by the average of beginning and ending inventory. Customer concentration is measured as the total share of annual sales from major customers. In order to test whether the ANOVA results are problematic due to the confounding effect of other firm characteristics, I conduct the cross-sectional regression and control firm-level characteristics which are commonly examined in other studies (Lang and Stulz, 1992; Erwin and Miller, 1998; Prokopczuk, 2010; Bhabra *et al*., 2011).

The regression analysis is also often adopted in event studies to further explain variations in the abnormal returns (MacKinlay, 1997, Hendricks *et al*., 2009, 2014, Thirumalai and Sinha, 2011). I adopt the Ordinary Least Square (OLS) estimation and construct the regression model as below:

$$CAR_i = \beta_0 + \beta_1 supply\ chain\ linkage_i + \beta_2 inventory\ turnover_i + \beta_3 customer\ concentration_i + \beta_4 book\ to\ market\ ratio_i + \beta_5 debt\ to\ capital\ ratio_i + \beta_6 firm\ size_i + \beta_7 ownership_i + \varepsilon_i$$

The dependent variable CAR_i is the cumulative abnormal return of firm *i* over the event window. The main explanatory variables are supply chain linkage with Japanese firms, inventory turnover, and customer concentration. Control variables are book-to-market ratio, firm size, debt-to-capital ratio, ownership which have been previously identified to influence firms' market value in literature of event studies (Hendricks *et al*., 2009; Lam *et al*., 2016; Thirumalai and Sinha, 2011). Specifically, supply chain linkage is measured as the count of the number of Japanese customers or suppliers, book-to-market ratio is the book value of a firm divided by its market value, debt-to-capital ratio is the total debt of a firm divided by the sum of shareholder's equity and total debt, firm size is measured as the logarithm of annual sales, and ownership is coded as the dummy variable indicating different ownerships. Table 3.1 lists all the variables, measurements, data source, and references in the cross-sectional analysis.

Table 3.1 Variables in the cross-sectional analysis

Data	Description		Source	References
Sample	All the 170 (134) firms listed in the Shanghai and Shenzhen Stock Exchanges and included in the Electronic parts and components sector according to the CITIC securities industrial classification		Wind	
Variables	Shareholder value	Daily stock return	Wind	(MacKinlay, 1997)
	Supply chain linkage	Count of the number of Japanese SC partners	Bloomberg	(Steven *et al*., 2014)
	Inventory turnover	Cost of goods sold (COGS) / average of beginning and ending inventory in the most recent fiscal year before the announcement year	CSMAR	(Hendricks and Singhal, 2009)
	Customer concentration	Total share of annual sales from major customers in the most recent fiscal year before the announcement year	Bloomberg	(Wagner and Bode, 2006), (Patatoukas,2011)
	Firm size	Log(annual sales) in the most recent fiscal year before the announcement year	CSMAR	(Hendricks and Singhal, 2009)
	Debt-to-capital ratio	Total debt of a firm/ (shareholder's equity + total debt) in the most recent fiscal year before the announcement year	CSMAR	(Lam *et al*., 2016) (Thirumalai and Sinha, 2011)
	Book-to-market ratio	Book value/ market value in the most recent fiscal year before the announcement year	CSMAR	(Hendricks and Singhal, 2001)
	Ownership	Dummy variable indicating different ownerships	CSMAR	

3.3 Results

3.3.1 Event study results

Table 3.2 Summary of (Cumulative) abnormal returns of Chinese semiconductor firms

Event Day(s)	*N*	Median (%)	Z_1	%Negative	Z_2
0	134	-0.216	-1.604	57.462%	-1.643
1	134	-0.694	-1.996**	59.701%	-2.165**
2	134	-1.028	-3.262***	66.418%	-3.745***
3	134	-0.329	-2.088**	57.463%	-1.643
4	134	-0.664	-2.798***	63.433%	-3.039***
(0,4)	134	-2.088	-3.880***	66.418%	-3.745***

Notes: Z_1-statistics for medians are obtained using Wilcoxon signed-rank tests
Z_2-statistics for negatives are obtained using binomial sign tests
Significance levels (two-tailed tests): '***'$p < 0.01$ '**'$p < 0.05$ '*' $p < 0.10$

Table 3.2 indicates that the stock market of Chinese semiconductor firms reacts negatively to the Japanese earthquake, suggesting that the negative contagion effect dominates in the full sample, supporting *H1a*. Because the mean results could be influenced by outliers and tend to be skewed in the relatively small sample, I emphasize median and percent of negative abnormal returns and conduct the non-parametric analysis. The median returns for each day of the 5-day event window are all significantly negative and more than half of the firms react negatively to the earthquakes. Specifically, all the test statistics are insignificant on the day of the Kumamoto earthquake (day 0) which is explainable as the earthquake occurred after the Chinse stock market was closed (occurred at 21:26, GMT+9 Time Zone). For the rest of the 4 days, all median abnormal returns are significantly negative. On day 2 (a 7.0 magnitude aftershock occurred), the median (-1.028% at a significance level of 0.01) is the most negative and 66.42% (at a significance level of 0.01) of the firms experience negative abnormal returns. Overall, considering a 5-day event window from day 0 to day 4, the median abnormal return is -2.088% (significance level of 0.01). The majority of the firms (66.42% with significance level of 0.01) react negatively to the earthquake.

3.3.2 Cross-sectional analyses results

Table 3.3 Difference in subsample of firms with different levels of inventory turnover and customer concentration

	# of firms with characteristics below/above sample median	Mean abnormal returns for the subsample(%)		Median abnormal returns for the subsample(%)	
		Below	Above	Below	Above
Inventory turnover ratio(ITR)	61/61	-2.788 (-4.868) ***	-0.071 (-0.110) [9.941] ***	-2.899 (-4.281) ***	-0.808 (-0.431) [-2.806] ***
Customer concentration	61/61	-2.198 (-3.996) ***	-0.661 (-0.952) [3.012] *	-2.119 (-3.570) ***	-1.515 (-1.113) [-1.628]
Customer concentration (Subsample of firms below median ITR)	32/29	-2.419 (-3.161) ***	-3.196 (-3.686) *** [0.455]	-2.331 (-2.910)***	-3.654 (-3.324)*** [-0.538]
Customer concentration (Subsample of firms above median ITR)	29/32	-1.955 (-2.434) **	1.637 (1.825) * [8.761] ***	-2.119 (-2.252)**	0.324 (1.424) [-2.648]***

t-scores of *t*-test for mean and *z*-score of Wilcoxon signed-rank test for median are in parentheses;
F-values of *F*-test for mean and *z*-scores of Mann-Whitney test for median for difference in subsamples are in brackets.
Significance levels (two-tailed tests): '***'$p < 0.01$ '**'$p < 0.05$ '*' $p < 0.10$

As discussed previously, the intra-industry transmission effect is the sum of negative contagion effect and positive competitive effect. Though the overall transmission effect is shown to be negative and dominated by the contagion effect, the results of ANOVA (Table 3.3) further indicate that the two effects simultaneously exist among subgroups with different firm characteristics. Specifically, I separate the sample into subsamples according to levels of customer concentration and inventory turnover. From the results of the two-way classification, I find that for firms with lower inventory turnover, and firms with lower customer concentration, they experience average shareholder value losses of -2.788%, and -2.198%, respectively. While for firms with relatively higher inventory turnover, and for firms with higher customer concentration, though the abnormal returns are still negative, they are not significantly different from zero. The results of two-way classification indicate that the Japanese earthquakes are bad news for the Chinese firms with relatively lower inventory turnover and lower customer concentration within the same industry. A two-way classification is conducted to investigate the interaction of customer concentration and inventory turnover. I find that, the abnormal return of Chinese firms with both higher customer concentration and higher inventory turnover is 1.637% and at significance level of 0.1, suggesting that firms with higher inventory turnover and higher customer concentration can actually benefit from the earthquakes due to the dominance of positive competitive effect. In contrast, the rest of the firms in the full sample are experiencing negative effect (most of them are significant) from the earthquakes.

Whereas I had 134 sample firms for the estimation of abnormal returns, the sample size in the cross-sectional regression was reduced to 106 in the regression analysis due to incomplete information of some firms on firm characteristics, I further exclude 3 outliers at 99% level. Table 3.4 presents the correlations among all the variables included in regression analysis and descriptive characteristics of firms. Table 3.5 presents the cross-sectional regression analysis results. I observe some significant correlations among explanatory variables in the correlation matrix (Table 3.4). Possible collinearity among variables induced by correlation of different disruption mitigation strategies could decrease reliability of estimated coefficients. Therefore, I check the Variance Inflation Factor (VIF) values of explanatory variables in the regression. The VIF for customer concentration is 1.574, for supply chain linkage is 1.684, and for inventory turnover is 1.173. All the values are below the 2.5 which is viewed as acceptable level by Hendricks and Singhal (2009). This result suggests that collinearity is not an issue in the research.

Table 3.4 Descriptive statistics and correlation matrix

	1	2	3	4	5	6	7	8	9	10	11
1. CARs	1										
2. Book-to-market ratio	0.204**	1									
3. Firm size	0.226**	0.440***	1								
4. Debt-to-capital ratio	-0.069	0.035	0.338***	1							
5. Ownership-State	0.164*	0.306***	0.115	0.004	1						
6. Ownership-Private	-0.073	-0.348***	-0.173*	0.061	-0.781***	1					
7. Ownership-Foreign	-0.102	0.113	0.122	-0.051	-0.166*	-0.451***	1				
8. Ownership-Other	-0.051	0.031	-0.018	-0.162	-0.053	-0.144	-0.031	1			
9. Supply chain linkage	0.047	0.410***	0.341***	0.156	0.127	-0.109	0.008	-0.041	1		
10.Inventory turnover	0.208**	0.147	0.322***	0.280***	0.082	-0.093	0.054	-0.061	0.166*	1	
11. Customer concentration	0.200**	0.214**	0.314***	0.267***	0.090	-0.141	0.121	-0.061	0.550***	0.210**	1
Mean	-0.018	0.160	21.26	0.373	0.223	0.680	0.087	0.010	0.524	5.060	0.127
SD	0.050	0.105	1.115	0.157	0.418	0.469	0.284	0.099	1.282	2.836	0.208

Significance levels (two-tailed tests): '***' $p < 0.01$ '**' $p < 0.05$ '*' $p < 0.10$

Table 3.5 Regression results

	Model 1	Model 2	Model 3	Model 4
Intercept	-0.235(-2.270)**	-0.248(-2.358) **	-0.221(-2.097)**	-0.201(-1.950)*
Book-to-market ratio	0.044(0.824)	0.057(1.004)	0.057(1.021)	0.067(1.229)
Firm size	0.011(2.190)**	0.012(2.271) **	0.010(1.887)*	0.009(1.734)*
Debt-to-capital ratio	-0.057(-1.702)*	-0.055(-1.635)	-0.067(-1.977)*	-0.081(-2.403)**
Ownership-Private	-0.010(-0.768)	-0.009(-0.760)	-0.008(-0.664)	-0.006(-0.525)
Ownership-Foreign	-0.035(-1.800)*	-0.035(-1.826)*	-0.036(-1.861)*	-0.040(-2.141)**
Ownership-Other	-0.049(-0.981)	-0.051(-1.006)	-0.048(-0.957)	-0.046(-0.940)
Supply chain linkage		-0.003(-0.720)	-0.003(-0.819)	-0.009(-1.916)*
Inventory turnover			0.003(1.859)*	0.003(1.746)*
Customer concentration				0.067(2.394)**
Number of observations	103	103	103	103
Model *F* value	2.176*	1.93*	2.164**	2.657***
R-square	0.120	0.125	0.156	0.205
Adjusted *R*-square	0.065	0.060	0.084	0.128

The dependent variable is the abnormal returns of an event window of (0, 4). Estimation window of (-160, -21).
Significance levels (two-tailed tests): '***'$p < 0.01$ '**'$p < 0.05$ '*' $p < 0.1$

The regression results shown in Table 3.5 suggests that all of the four different hierarchical regression models are significant ($F > 1.93$, $p < 0.1$) with Adjusted R-square ranging from 0.060 to 0.128 which is acceptable considering the case of cross-sectional regression. Model 1 is the basic model including only control variables. In Model 2 to 4, explanatory variables of firm characteristics are gradually added. Supply chain linkage is insignificant in Model 2 and 3, potentially because of the negative confounding effect of customer concentration and inventory turnover. However, supply chain linkage becomes significantly negative in Model 4. All of the explanatory variables are significant (significance level at 0.1 and 0.05) in two-tailed tests in Model 4. The results indicate that firm characteristics of supply chain linkage, inventory turnover, and customer concentration play a significant role in affecting the transmission effect of exogenous shocks such as earthquakes.

Specifically, I expect that firms with Japanese supply chain partners will experience greater market value loss due to more pronounced negative contagion effect (*H2*). The results support this expectation. The results show that the coefficient of supply chain linkage is -0.009 at significance level of 0.1 in two-tailed tests (Model 4), indicating that supply chain linkages are well captured by investors as signals of future underperformance of Chinese firms. The coefficient of inventory turnover is 0.003 at a significance level of 0.1 in two-tailed test, showing that the firms with high inventory turnover experience less negative market value loss, consistent with *H3*. Lastly, I have argued that firms with concentrated customers achieve better operating efficiency and reduced operating risks *(H4)*. The coefficient of customer concentration is 0.067 at significance level of 0.05 in two-tailed test (Model 4). All the three hypotheses of the moderating effect of firm-level characteristics are supported.

3.3.3 Sensitivity analysis

Table 3.6 Sensitivity analysis within different event periods using Fama-French-Five-Factor Model

	Estimation window	Event window	N	Mean CAR(%)	T	Median CAR(%)	Z_1	Negative CAR (%)	Z_2
1	-160 -21	0 4	134	-1.589	-1.908**	-2.088	-3.880***	66.42%	-3.57***
2	-160 -21	0 5	132	-1.741	-1.936*	-2.209	-4.308***	69.697%	-4.494***
3	-160 -21	0 10	131	-2.172	-1.856*	-2.216	-4.329***	64.886%	-3.342***

T-statistics for means are obtained using Portfolio approach
Z_1-statistics for medians are obtained using Wilcoxon signed-rank tests
Z_2-statistics for negatives are obtained using binomial sign tests
Significance levels (two-tailed tests): '***' $p < 0.01$ '**' $p < 0.05$ '*' $p < 0.1$

In order to further enhance the robustness of the results and reveal a comprehensive picture of the consequences of the disaster, I conduct additional analysis over different event windows: (0, 4), (0, 5), (0, 10). Table 3.6 shows that the cumulative abnormal returns are all significantly negative over the event windows of (0, 4), (0, 5), (0, 10), indicating that the negative market reaction is robust and persistent. Figure 3.2 and 3.3

depict the trend of cumulative abnormal returns for different event windows and daily abnormal returns for different days, respectively. Figure 3.2 indicates that although there are some fluctuations around five-day event period, the cumulative abnormal returns are generally well below zero and there is a downward trend in a 16-day period after the earthquake occurs. The cumulative abnormal returns remain significantly negative for 15 consecutive days (from day 0 to day 14). Figure 3.3 shows that during the 16-day event window, except day 4 and day 6, abnormal returns for the other 13 days are negative.

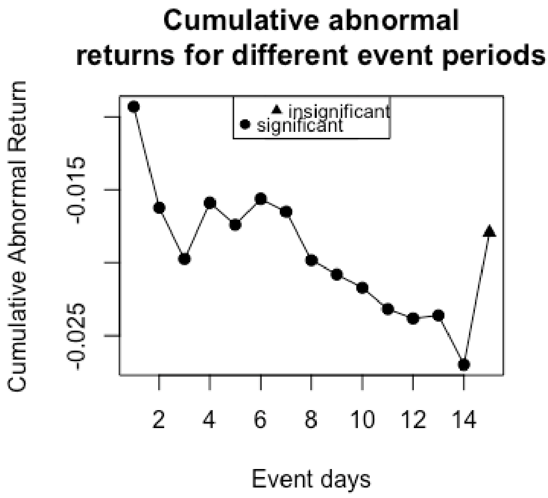

Figure 3.2 Cumulative abnormal returns over different event windows

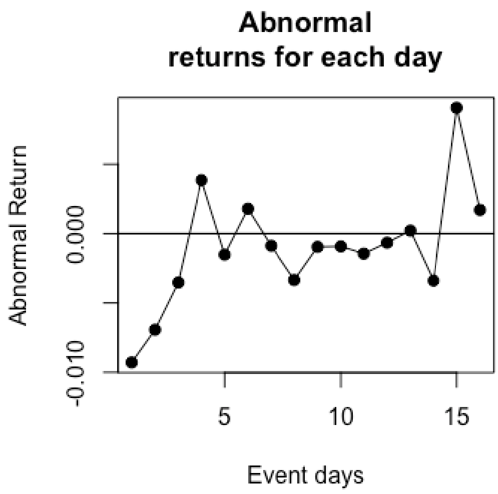

Figure 3.3 Abnormal returns for each day in the event window of (0, 15)

3.4 Conclusion and discussions

This paper first examines the transmission effect of the exogenous disaster on firms within the same industry across national borders. My study provides empirical evidences for the contagion and competitive effect of Japanese earthquakes on Chinese industry peers. For the full sample, negative contagion effect will dominate and transmit across countries within the same industry. However, for the subsamples with different firm characteristics, I find that the negative contagion effect and positive competitive effect simultaneously exist. Specifically, from the operational efficiency perspective, I find that firms with higher inventory turnover and higher customer concentration benefit from the misfortune in Japanese firms.

The negative transmission discovered in this research calls for more attention on the impact of natural disasters, especially in a global supply chain where partners are broadly linked and disruptions are more likely to occur. Although broad consensus has been reached on the negative effect of supply chain risks, some debates exist and argue that the negative effect of natural disasters might have been overestimated due to their low frequency of occurrence. For example, Wagner and Bode (2008) empirically investigate the effect of various types of risks on supply chain performances and conclude no significant negative impact from catastrophic disruptions. In contrast, the study shows that over a five-day event period, Chinese semiconductor firms suffer 1.59% significant shareholder losses on average. The negative effect lasts for 15 trading days after the occurrence of the earthquake. The contradictory conclusion can be due to the different research context. Specifically, Wagner and Bode's (2008) study is based on Germany companies with a coverage of both minor and significant catastrophic disruptions. However, this case is different in terms of the risk profile and disaster type. Japan is a country with a notorious earthquake history and the production facilities and transportation which are vital to semiconductor industry are extremely vulnerable to the 7.0 magnitude earthquake. In general, though with low frequency, natural disasters should not be ignored due to its potential in generating widespread and long-term negative impact.

The results also indicate that global expansion is not free, greater risks come along with increased business opportunities. It is shown that the market reaction of Chinese semiconductor firms with Japanese supply chain partners is more negative compared with those without Japanese partners. The result provides empirical evidences suggesting that the supply chain linkages function as the transmission mechanism proposed by Carvalho *et al*. (2016). The supply chain linkages were recognized by investor as potential causes for future profit losses caused by halt of production, change of demand, shortage of supply and so on. In a global supply chain, firms interconnected in a wide network making themselves increasingly vulnerable to disruptions (Manuj and Mentzer, 2008). Disruptions which occur anywhere in the network could create a widespread impact through the upstream and downstream linkages. Compared with firms with a domestic supply chain, firms with a global supply chain encounter greater uncertainties and risks and are more prone to supply chain disruptions.

Last but not least, this study also indicates that firms with greater operational efficiency can reap the benefits from the difficulties experienced by their industry peers. As previously discussed, firms with higher inventory turnover and higher customer concentration achieve better efficiency from the reduced inventory holding cost, increased net cash flow, enhanced information sharing and coordination. Consequently, they can better exploit the competitive position and increase the shareholder value even though the rest of the Chinese firms are negatively affected. The argument of efficiency challenges the conventional view of supply chain risk mitigation to some extent. Broader customer base and inventory slack and are usually regarded as strategies used to prevent substantial losses arising from supply chain risks (Peck and Christopher, 2003; Chopra and Sodhi, 2004; Kleindorfer and Saad, 2005; Tang, 2006; Jüttner *et al*., 2003; Tomlin, 2006; Hendricks *et al*., 2009). However, different from the context of firm-specific disruptions, the mitigation effect of flexibility coming from switching between different customers could be very limited if the entire industry is being affected by the common shock, i.e. the earthquake. Moreover, Back-up inventory prepared for frequently occurred disruptions like the machine breakdown can hardly protect firms against the consequences of the earthquake. Worse still, carrying excessive inventory usually comes with holding costs and financial risks. In addition to the costs of warehousing, labor, insurance etc., occupied money investment in inventory and failure to turn it into revenue will increase firm's financial risks and make it less flexible to cope with disruptions (Tomlin and Wang, 2011).

There are some possible extensions for future research to address the limitations of the study. First, this study focuses on the industry-wide impact of the Japanese earthquake on Chinese semiconductor firms. Owing to data limitations, I am not able to discern the competitors and sub-tier partners of Japanese firms. With proposed opposite contagion and competitive effects among firms with different characteristics, future research could empirically examine whether the reactions will be different among direct partners, sub-tier partners, and competitors. Second, future study could investigate how companies in other emerging economies which are considered to have a lower status in the value chain react to an exogenous shock. Generalized conclusions might be reached from consistent results that firms in emerging economies are more vulnerable to exogenous shocks than those in developed countries.

Chapter 4 Study Three: The Performance Implications of 3D Printing Implementation: An Event Study[2]

4.1 Literature review and hypotheses development

4.1.1 3DP technology

Most of the extant research about 3DP has primarily focused on its technological advancements and industrial applications (Lam *et al.*, 2002; Ventola, 2014; Williams *et al.*, 2010). Although the manufacturing process of 3DP may use different printer technologies or printing materials, the basic steps remain the same: (1) A computerized 3D model of the object to be manufactured is developed in a computer-aided design (CAD) file. (2) The printer follows the instructions of the CAD file to build a foundation of the object by moving the printhead along the *x*-*y* plane. (3) The printhead then moves along the *z*-axis to add materials layer by layer. The additive manufacturing process differs from conventional manufacturing techniques which subtract materials from a larger piece (Ventola, 2014). While 3DP has attracted extensive attention from media, industry, and academia since 2013, the technology is not in its infancy when it comes to manufacturing applications. 3DP has been adopted by manufacturers as a complementary technology for rapid prototyping since 1980s (Huang *et al.*, 2012). About thirty years into its development, 3DP has revealed great potential as a direct manufacturing technique in various contexts including repairing existing products, manufacturing tools and machine parts, and manufacturing end-use components and products (Thomas-Seale *et al.*, 2018).

[2] Most part of this chapter was published in *International Journal of Operations & Production Management, Volume 39, December 2019, Page 935-961.*

Studies seeking to understand the implications of 3DP start to emerge in recent years (Dong *et al.*, 2017; Huang *et al.*, 2012; Petrick and Simpson, 2013; Weller *et al.*, 2015; Jiang *et al.*, 2017; Khorram Niaki and Nonino, 2017; Shukla *et al.*, 2018; Eyers *et al.*, 2018; Golini *et al.*, 2015; Jia *et al.*, 2016). On one hand, these studies provided preliminary discussions about the advantages of 3DP such as accelerating product development, offering customized products, and increasing production flexibility. For instance, Huang *et al.* (2012) claimed that 3DP by nature eliminates the need for tooling, molding, warehousing, transportation, and packaging. The simplified supply chain leads to improved material efficiency, resource efficiency, part flexibility, and production flexibility, thus enabling on-demand manufacturing. Weller *et al.* (2015) discussed the economic implications of 3DP on market structure. They argued that 3DP intensifies competition in competitive markets. As 3DP reduces the capital costs required to start production, it facilitates firms to diversify their business and enter into multiple markets. Whereas in monopoly markets, firms adopting 3DP are able to charge price premiums due to increased customization and functional improvement. Shukla *et al.* (2018) discussed the impact of 3DP on mass-customization and proposed that 3DP facilitates four key practices in mass-customization including agility, customer involvement, postponement (i.e. “print-to-order”), and modularization. Dong *et al.* (2017) conducted one of the few analytical studies about the optimal manufacturing strategy under traditional flexible technology and 3DP. They proved that, compared with traditional flexible technology, 3DP excels in enhancing product diversity by allowing firms to choose a large product assortment with little profit loss.

On the other hand, previous studies also indicated that 3DP has not been accepted as a standard production technology due to limitations including technological constraints, investment costs, and business challenges (Attaran, 2017; Shukla *et al.*, 2018; Thomas-Seale *et al.*, 2018; Weller *et al.*, 2015). First, compared with conventional subtractive manufacturing, additive manufacturing lacks economy of scale. Economy of scale exists in conventional subtractive manufacturing because increased volume of mass production reduces the portion of fixed-cost in the cost equation, thus reducing per-unit cost. However, different from conventional injection molding, the production throughput speed of the additive manufacturing process is rather low, so 3DP is mostly adopted in multi-variant and low-volume production (Petrick and Simpson, 2013). Second, the limitations of printing materials, colors, and surface finishes could impede broader applications of 3DP (Petrick and Simpson, 2013; Weller *et al.*, 2015). For example, at current stage, additive manufacturing still cannot compete with the subtractive manufacturing in terms of precision. Shukla *et al.* (2018) suggested that 3DP can only produce with the accuracy up to 0.2 millimeters. As a result, significant efforts are required for the polishing and finishing surfaces afterwards. Third, the purchasing cost for a single 3D printer is unneglectable, ranging from approximately 5,000 to 50,000 USD, not to mention additional costs including supporting machinery, printing materials, and highly skilled personnel (Huang *et al.*, 2012; Shukla *et al.*, 2018). Last but not least, "soft barriers" such as the lack of technological know-how (Thomas-Seale *et al.*, 2018), CAD software complexity (Shukla *et al.*, 2018), possible copyright infringement (Bogers *et al.*, 2016), and unestablished global quality and test standards (Weller *et al.*, 2015) may also hinder the implementation of 3DP.

4.1.2 An operational scope perspective on 3DP

In light of the implications discussed above, I introduce the notion of operational scope with the aim of associating 3DP with firms' capability to broaden operational scope. Previous studies generally identify operational scope as a multi-dimensional concept, comprised of product/service scope, geographic scope, and process scope (Chatain and Zemsky, 2007; Clark and Huckman, 2011; Denis *et al.*, 2002; Hitt *et al.*, 1997; Kovach *et al.*, 2015). Product/service scope is the breadth of the product/service portfolio offered by a firm (Clark and Huckman, 2011; Kovach *et al.*, 2015). Geographic scope is the breath of expansion into different geographic locations or markets (Hitt *et al.*, 1997; Kirca *et al.*, 2011). Process scope is the level of flexibility to cope with the change in output (Anand and Ward, 2009; Kovach *et al.*, 2015; Szwejczewski *et al.*, 2009). A consensus has been reached concerning the trade-off between operational scope and efficiency in existing research (Clark and Huckman, 2011). It has been well acknowledged that diversification is not free, and expanding operational scope almost inevitably increases operational complexity and inflates costs (Hitt *et al.*, 1997; Ramdas, 2009).

3DP potentially challenges the conventional wisdom as it implies increased operational scope without cost penalties, thus realizing economy of scope (Petrick and Simpson, 2013; Schniederjans, 2017; Weller *et al.*, 2015). Specifically, first, 3DP expands product scope through cost-effective and time-efficient product innovation, customization and intricacy (Shukla *et al.*, 2018; Weller *et al.*, 2015). Traditionally, offering a diverse product portfolio incurs additional operational costs such as tooling, manufacturing capability investments, and variety-related inventory holding costs (Kovach *et al.*, 2015). However, as there are no tolling requirements nor minimum batch size pressure in the one-step additive manufacturing process, diversified product design can be achieved without additional tooling costs or inventory holding of a large variety of products (Weller *et al.*, 2015). Moreover, 3DP enhances new product development by removing the restrictions of innovation. 3DP can be used to manufacture any sophisticated parts that can be imaged without the need to compromise on the functionality for the ease of manufacturing (Attaran, 2017). Beyond manufacturing settings, 3DP has also been adopted to provide services of producing 3D printed items for customers, mostly in healthcare, retailing, logistics and transportation industries (Ernst & Young, 2016). For example, Henry Schein, a worldwide dental supplier, provided 3D-printed mouth guards for their customers using intra-oral scanners (Bloomberg, 2017). In 2014, Amazon started to offer 3D printing services that allow customers to customize items such as earrings and toys (Seetharaman, 2014). UPS, aside from package delivery service, has expanded its service scope to provide 3DP services in UPS stores since 2013.

Second, 3DP expands the geographic locations where firms produce and sell products through decentralized manufacturing (Attaran, 2017). With a 3D printer, customers are allowed to download digital models from websites, and then additively manufacture the parts in need by themselves at almost any locations. Manufacturing at the point of use is expected to reduce the requirement of extensive physical inventory and large-volume logistics and transportations. For instance, Ford launched an online 3DP store to provide 3DP services that allow customers to "print" the scale automotive models with the digital models download from their website.

Third, 3DP achieves broad process scope with increased production flexibility. Process scope is associated with both mix flexibility and volume flexibility (Kovach *et al.*, 2015). 3DP increases mix flexibility in the manufacturing process as any changes of design are allowed by simply modifying the 3D model stored in the CAD file. Moreover, 3DP enables direct manufacturing without the need for tools or molds, so the design changes can be easily transferred into production (ErnstYoung, 2016). Additionally, 3DP substantially reduces manufacturing steps by removing the processes of casting, molding, machining, and assembly, thus reducing manufacturing costs. The negligible changeover costs and simplified manufacturing steps contribute to the increased flexibility of adjusting production according to varying designs, sequences, or volumes (Weller *et al.*, 2015).

Overall, in line with practitioners' collective belief that 3DP is a promising technology to achieve competitive advantage (Ernst & Young, 2016; Hartmann *et al.*, 2015; Geissbauer *et al.*, 2017), I expect 3DP implementation to enhance firms' performance by broadening their operational scope. In this research I employ the event study method to quantify the performance impact of 3DP implementation in terms of stock returns, for several reasons. First, as the implementation of 3DP varies greatly across industries such as healthcare, automotive manufacturing, fashion, consumer products, and aerospace, it is difficult to determine appropriate operational performance measures that fit in all contexts of different types of implementation. Stock returns, on the other hand, represent the overall assessment of a firm's value, taking account of all information available in the market (Sorescu *et al.*, 2017), thus more likely to capture the overall performance impact due to 3DP implementation. In fact, stock returns have been widely used as an appropriate measure of firm performance in different industries (Barber and Lyon, 1997; Hendricks and Singhal, 2001). Moreover, the event study method enables us to compare the stock returns of firms implementing 3DP with that of their matched industry peers who have not implemented 3DP, helping address the heterogeneity of 3DP implementation across industries. As a result, I anticipate that 3DP implementation enables firms to broaden their operational scope, leading to improved firm performance and indicated as positive stock returns. Therefore, I hypothesize that:

H1: Firms' 3DP implementation has a positive impact on their stock returns.

4.1.3 Operational scope and industry environments

I believe that the effectiveness of 3DP is unlikely to be consistent across industries as broadening operational scope does not necessarily improve firm performance in all industries (Benito-Osorio *et al.*, 2012; Ramdas, 2009). Mixed empirical evidence of the relationship between operational scope and firm performance was discovered ranging from positive linear relationship (Anand and Ward, 2009), negative linear relationship (Clark and Huckman, 2011; Denis *et al.*, 2002), to inverted U-shape non-linear relationship (Hitt *et al.*, 1997; Narasimhan and Kim, 2002). As proposed by Benito-Osorio *et al.* (2012), the heterogeneity in conclusions may result from different theoretical perspectives, performance measures, and research contexts. Additionally, given the heightened likelihood that some firms are chasing the "3DP hype" regardless of the alignment between the technological features and their operational strategy, these firms might underperform in years subsequent to the implementation.

The mixed results presented in the operational scope research indicate that the association between operational scope and firm performance may depend on the environmental conditions (Anand and Ward, 2009; Benito-Osorio *et al.*, 2012; Clark and Huckman, 2011; Pagell and Krause, 2004; Vokurka and O'Leary-Kelly, 2000). For instance, Anand and Ward (2009) showed that increased manufacturing flexibility better predicts improved business performance of manufacturing firms in more dynamic environments, whereas Pagell and Krause (2004) found the relationship to be insignificant and argued that the conclusion is not generalizable to different industries.

Through the lens of operational scope, I argue that the stock returns due to 3DP implementation will be moderated by the industry environments in which the firms operate. To characterize the industry environments, I followed previous studies and identified three industry environmental characteristics, namely munificence, dynamism, and competition that are relevant to the research context (Boyd, 1990; Dess and Beard, 1984; Xia *et al.*, 2016). By examining the environmental moderators, I can determine whether the effectiveness of 3DP would be affected by the fit between the capabilities enhanced by 3DP and industry environments. Figure 4.1 presents the conceptual framework of this study.

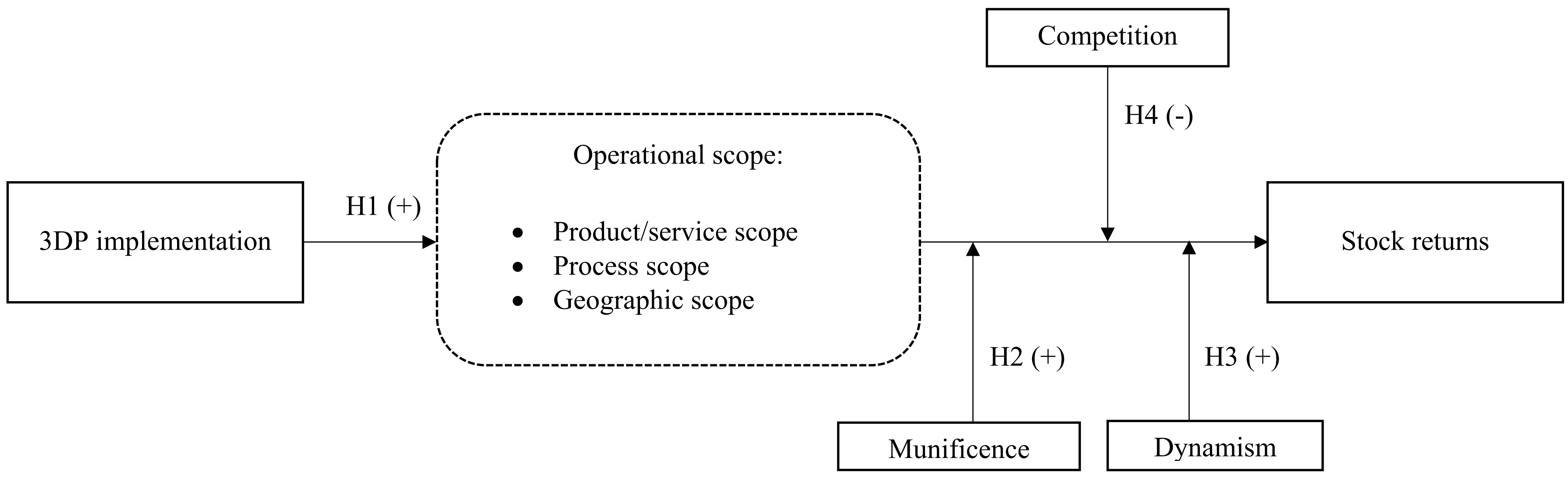

Figure 4.1 Conceptual framework

Industry munificence refers to the level of resources available to support the sustained growth of the firms in the industry (Boyd, 1990; Dess and Beard, 1984; Lester *et al.*, 2005; Park and Mezias, 2005). It is primarily determined by the rate of sales growth in the industry (Dess and Beard, 1984). In an industry with high level of industry munificence, firms are more likely to accumulate slack resources such as venture capital, government funds, labor markets, and suppliers (Dess and Beard, 1984; Park and Mezias, 2005). Dess and Beard (1984) indicated that these slack resources not only function as buffer during times of scarcity, but also facilitate organizational innovation. Firms implementing 3DP in munificent industries are more likely to gain benefits because the effectiveness of 3DP depends on the availability of several critical resources such as qualified experts, software vendors, investment capitals (Huang *et al.*, 2012; Shukla *et al.*, 2018; Thomas-Seale *et al.*, 2018). On the contrary, firms in the industry with low level of munificence could encounter several obstacles preventing them from accessing the resources for development. These obstacles may include tax burdens, fragile infrastructure, inaccessible to technology support from educational institutions, lack of qualified labor, and economic turndown *etc.* (Chen *et al.*, 2014). In general, 3DP implementation is more likely to be effective when firms are operating in more munificent industries (Chen *et al.*, 2014; Terjesen *et al.*, 2011). Thus I hypothesize that:

> *H2: The stock returns of 3DP implementation will be positively related with the level of industry munificence.*

Industry dynamism refers to the instability of the environment (Dess and Beard, 1984; Jansen *et al.*, 2006). Dess and Beard (1984) further emphasized that dynamism should be restricted to the changes which are unpredictable. Dynamic industries are characterized as changeable customer preferences, unpredictable technology development, fluctuated market demand, and inconstant government regulations (Anand and Ward, 2009; Stoel and Muhanna, 2009). Anand and Ward (2009) indicate that in order to cope with a large number of unpredictable scenarios, firms are required to broaden process scope by maintaining diverse capabilities and building up excess capacity, which inevitably leads to higher costs. As a result, manufacturing flexibility plays a significant role in gaining competitive advantage in dynamic industries. Firms investing in 3DP are allowed to move between different product designs and production volumes with less incurring time and cost penalties, and thus are likely to gain greater advantages. Similar to Stoel and Muhanna's (2009) argument about externally-oriented IT, I believe that the effectiveness of 3DP is more pronounced in dynamic environments in that it enables firms to better sense the market through customization and timely respond to the fluctuations in customer and supplier demand. Overall, I concur researchers' opinion that 3DP is most advantageous in industries characterized by uncertainty, high product variety, and fluctuating customer preferences (Weller *et al.*, 2015). Therefore, I hypothesize that:

> *H3: The stock returns of 3DP implementation will be positively related with the level of industry dynamism.*

Industry competition refers to intensity of competition in the industry, often reflected in the number of competitors and the concentration of market shares (Jansen *et al.*, 2006; Melville *et al.*, 2004). Low level of concentration represents a competitive market with market shares almost evenly distributed among a large number of competitors, while high level of concentration depicts a monopoly or oligopoly industry with a small number of competitors dominating the market (Azadegan *et al.*, 2013). I argue that the implementation of 3DP could enhance firm's differentiation capabilities, consequently generating greater profits in less competitive markets. Specifically, 3DP facilitates product innovation by eliminating the iteration costs and manufacturing limitations in the product design process (Weller *et al.*, 2015). 3DP also enables customization without cost penalties, consequently increasing customers' perceived values and higher willingness to pay (Shukla *et al.*, 2018). Under high competitive pressure, it is particularly difficult for firms to sustain the advantages of differentiation due to low entry barriers and market-determined prices. The first-mover advantages from the implementation of 3DP could also fade with the technology diffused among competitors over time (Jansen *et al.*, 2006; Melville *et al.*, 2004). However, in monopoly or oligopoly industries, the entry barrier is high enough to deter potential market entrants. Dominant players have strong power to charge a price premium which is not allowed in competitive market. Weller *et al.* (2015) proposed that "in monopoly, the adoption of additive manufacturing allows a firm to increase profits by capturing consumer surplus when flexibly producing customized products." Therefore, I hypothesize that:

> *H4: The stock returns of 3DP implementation will be negatively related with the level of industry competition.*

4.2 Methodology

4.2.1 Data

A firm's implementation of 3DP could be in different contexts such as rapid prototyping, manufacturing end-use products, and providing 3DP services. The focus of this paper is to investigate all types of implementation of 3DP technology in firms. First, I attempt to identify the population of U.S.-listed firms that publicly announced the implementation of 3DP. I conducted a comprehensive search in the Factiva database with 3DP related keywords to collect firm announcements of 3DP implementation across all industries between 2010 and 2017. Factiva is one of the largest and most frequently used databases for business search, with a wide coverage of business information from newspapers, magazines, blogs, reports, websites *etc.* The keywords used in this study are (NASDAQ or NYSE or AMEX) and (3D print* or three-dimensional print* or additive manufactur* or rapid manufactur* or rapid prototyp*). The preliminary search generated 2894 announcements, and then I review each announcement to ascertain that they meet the following criteria. (1) The announcement should be related to applying 3DP technology to the firm's business practices such as product design and development, rapid prototyping, specialized manufacturing, service providing and other related activities. Announcements only informationally associated with 3DP without applications were excluded. For example, the announcement about Staples becoming the first U.S. retailer to sell 3D printers was eliminated. (2) Duplicated announcements reporting the same event were excluded. (3) Announcements made by private firms or firms not listed in NYSE, AMEX, or NASDAQ were excluded. The process resulted in 242 announcements made by 132 firms. For further matching process, I exclude 7 firms without data in Compustat and 3 firms with negative market-to-book ratios. The final sample consists of 232 announcements made by 122 firms. Some examples of the announcements are shown below.

- Under Armour's 3D-printed shoes bring computer designer to heel.
- Ford begins large-scale 3D printing trial.
- Amazon offers 3D printing to customize earrings, bobble head toys.
- UPS store makes 3D printing accessible to start-ups and small business owners.

Table 4.1 Distribution of 3DP announcements

Distribution of announcements across years			
Year	No. of announcements	Percentage	
2010	4	2%	
2011	5	2%	
2012	9	4%	
2013	25	11%	
2014	42	18%	
2015	41	18%	
2016	61	26%	
2017	45	19%	
Total	232	100%	
Distribution of announcements across industries			
Industry	SIC	Number	Percentage
Agriculture, Mining, Construction	0100-1999	5	2%
Food, textiles, furniture, paper, and chemicals	2000-2999	34	15%
Rubber, leather, stone, metals, machinery, and equipment	3000-3569, 3580-3659,3800-3999	57	25%
Computers, electronics, communications, and defense	3570-3579, 3660-3699, 3760-3789	37	16%
Automobile, aircraft, and transportation	3700-3759, 3790-3799	24	10%
Transportation, communications, wholesaling and retailing	4000-5999	22	9%
Services and non-classifiable	6000-9999	53	23%
Total		232	100%

Table 4.1 presents the distributions of the announcements across years and industries. As seen in Table 4.1, the majority (81%) of the announcements were made in the recent four years from 2014 to 2017, indicating soaring adoption rates. Most of the announcements (66%) are from manufacturing industries, while the remaining are from service industries or others.

4.2.2 Long-term event study method

Long-term event study measures the effect of an event by examining abnormal changes in stock returns over a long time period usually from one to five years (Kothari and Warner, 2007). Within my research context, the stock market may fail to reveal the true intrinsic value of 3DP implementation within a short time period. Specifically, immediately after the announcements were made, the investors possibly over-react to the 3DP implementation due to over-optimism and limited knowledge. In an investigation of e-commerce, Ferguson *et al.* (2010) argued that the stock market may overprice the added value of technologies which are regarded as innovative, exciting, and glamorous. Similarly, I believe that there could also be an upward bias in investors' valuation of 3DP, which is perceived as a groundbreaking technology to disrupt the conventional manufacturing. In addition, although 3DP technology was invented about 30 years ago, it has attracted public attention only since 2013 due to its burgeoning applications in end-use product manufacturing and mass-customization. As Hendricks and Singhal (2001) indicated in a study of TQM, the market may wait for more information to incrementally acquire knowledge about the new technology and judge its effectiveness. Therefore, I adopt the long-term event study method to examine the stock returns due to the implementation of 3DP which is a pioneering technology with relatively little knowledge of its value.

For the long-term event study, I calculate the abnormal stock returns as the buy-and-hold return (BHR) of the sample firms less the BHR of an appropriate benchmark (Barber and Lyon, 1997; Lyon *et al.*, 1999). The buy-and-hold abnormal return (BHAR) is

$$\text{BHAR} = \prod_{t=1}^{T}(1 + R_{it}) - \prod_{t=1}^{T}(1 + R_{bt}),$$

where R_{it} is the monthly stock return of the sample firm i in month t, R_{bt} is the monthly stock return of the control firm paired with sample firm i in month t, and T is the length of the event window. Monthly stock returns are retrieved from The Center for Research in Security Prices (CRSP) database. The conventional t-test is deployed to test the null hypothesis that the mean BHAR equals to zero. To account for possible extreme values of BHAR, non-parametric tests for the median and percentage of positive values of BHAR are also reported.

In developing the benchmark, I follow the standard procedures proposed in previous research (Barber and Lyon, 1997; Hendricks and Singhal, 2001) and match each sample firm to a control firm based on different combinations of three widely-accepted characteristics, namely industry, size, and market-to-book (MTB) ratio. The control firm approach has advantages in eliminating new listing bias, rebalancing bias, and the skewness problem compared with the portfolio approach (Barber and Lyon, 1997). With the reference to Hendricks and Singhal (2001), I particularly controlled the effect of industry given my specific research context. In fact, not only the implementation contexts, but also the maturity level and magnitude of sustainability benefits of 3DP vary across industries (Thomas-Seale *et al.*, 2018). Therefore, I emphasize industry as an important matching criteria to control the heterogeneity across industries. I use all the NYSE, NASDAQ, AMEX listed firms without 3DP implementation announcements as the benchmark pool. Industry is indicated by the firm's primary SIC code, size is measured as the market value of equity, and MTB ratio is calculated as market value of equity divided by book value of equity. All the accounting data are in the most recent fiscal year prior to the announcement year and were retrieved from the Compustat database. To check the sensitivity of my results, I take three different matching approaches to identify the control firm for each firm-year observation: (1) For the industry-size match, I first match a sample firm to control firms with the same four-digit SIC code, then the control firm closest in size is identified. If the control firm is not found, I match the sample firm to control firms with the same three-digit SIC code. The control firm must have at least same two-digit SIC code as the sample firm and is closest in size. (2) For industry-MTB match, I follow similar procedures as in the industry-size match, but the control firm closest in MTB ratio is identified. (3) For industry-size-MTB match, I follow similar procedures as in the industry-size match, but the control firm closest in the absolute percentage difference between size and MTB ratio is identified.

I set the calendar month when the announcement was made public as the event month 0. The first month after the event month is denoted as month 1, and the month before the event month is denoted as month -1. In reality, it usually takes several months for firms to finish the implementation of the 3DP equipment, to integrate 3DP into its traditional manufacturing process, or to promote 3DP services to a variety of audience. As a result, the effectiveness of 3DP implementation may not manifest until a few months after the announcement month. I thus set the implementation period as successive months after the announcement month. However, as there is little guidance in the literature regarding the appropriate time period for implementation of 3DP, I determine the length of implementation period based on the evidence provided in sample announcements. For example, Mattel Inc. announced on April 20, 2016 that they start a collaboration with Autodesk Inc. to power the Mattel toy line with cutting-edge 3D printing technology. Ten months later, Mattel introduced their 3D printing eco-system named ThingMaker to enable consumers to design, create, and print their own toys (Business Wire, 2015). Based on the information in the announcements and previous long-term event studies (Hendricks and Singhal, 2001), I set month (1, 12) as the time period required for implementation. Although existing studies about the technology implementation could measure the market performance over a long time ranging from one year to five years (Kothari and Warner, 2007), in the case of 3DP, I do not have the luxury to expand the post-implementation period because most of the announcements were released in recent three years between 2014 and 2017. Long post-implementation periods may capture the effect of 3DP implementations more extensively but also reduce the sample size substantially. To strike a balance, I set the post-implementation period as month (13, 24). I measure the effect of 3DP implementation over both implementation and post-implementation periods, i.e. month (1, 18) and month (1, 24), to fully capture the market reaction. Month (-24, -1) is set as the pre-implementation period.

4.2.3 Cross-sectional analysis

Table 4.2 Variables in the cross-sectional analysis

Variable Type	Variable Name	Measurement	Data source	Reference
Dependent Variables	BHAR	Abnormal buy-and-hold stock return calculated with monthly return BHAR = $\prod_{t=1}^{T}(1 + R_{it}) - \prod_{t=1}^{T}(1 + R_{bt})$	CRSP	(Lyon *et al.*, 1999)
Explanatory variables	Industry munificence	Industry munificence = the slope coefficient obtained by regressing sales over the time period of 2010-2017 / mean sales over the same time period	Compustat	(Dess and Beard, 1984) (Jacobs *et al.*, 2015)
	Industry dynamism	Industry dynamism = Standard error of the slope coefficient obtained by regressing sales over the time period of 2010-2017 / mean sales over the same time period	Compustat	(Dess and Beard, 1984) (Jacobs *et al.*, 2015)
	Industry competition	1-Herfindahl index = 1- $\sum_{i}^{N}(\frac{Sales_i}{Total\ Sales\ of\ firms\ in\ the\ same\ industry})^2$	Compustat	(Xia *et al.*, 2016) (Jacobs and Singhal, 2014)
Control variables	Firm size	Firm size = natural logarithm of market value of equity in the most recent fiscal year before the announcement year	Compustat	(Hendricks and Singhal, 2008)
	Prior performance	Prior performance = Sample firm ROA – median values of ROA of firms with the same 3-digit SIC code	Compustat	(Swink and Jacobs, 2012)
	MTB ratio	MTB = market value of equity/book value of equity in the most recent fiscal year before the announcement year	Compustat	(Hendricks and Singhal, 2001)
	R&D intensity	R&D intensity = R&D expenses / Sales in the most recent fiscal year before the announcement year	Compustat	(Jacobs *et al.*, 2015)
	Capital structure	Capital structure = Total liabilities / Sales in the most recent fiscal year before the announcement year	Compustat	(Chari *et al.*, 2007)
	Momentum	Momentum = Preannouncement buy-and-hold return of sample firms from 6 months to 1 month prior to the announcement month	CRSP	(Qian and Zhu, 2017)

Variable Type	Variable Name	Measurement	Data source	Reference
	Velocity	Fast velocity industry = cosmetics (SIC 284); computers and office machines (SIC 357); electronic components (SIC 367); computer programming (SIC 737); Low to medium velocity industry = other industries	Compustat	(Jacobs and Singhal, 2014) (Jacobs *et al.*, 2015)
	Type	Manufacturing industries = 1 Service and other industries = 0	Compustat/ Announcements	(Swink and Jacobs, 2012)
	Announcement year	Dummy variable	Announcements	(Hendricks and Singhal, 2003)

In addition to measuring the overall stock returns due to the implementation of 3DP, I also aim to investigate the moderating role of environmental factors. To explore the moderating effect, I employed the hierarchical regression analysis. Table 4.2 presents the measures, data sources, and references of the variables in the regression analysis.

$$\begin{aligned} BHAR_i = \ & \beta_0 + \beta_1 Firm\ size_i + \beta_2 MTB\ ratio_i + \beta_3 R\&D\ Intensity_i \\ & + \beta_4 Prior\ performance_i + \beta_5 Capital\ structure_i \\ & + \beta_6 Momentum_i + \beta_7 Velocity_i + \beta_8 Type_i + Year\ dummies \\ & + \beta_9 Munificence_i + \beta_{10} Dynamism_i + \beta_{11} Competition_i + \varepsilon_i \end{aligned}$$

The dependent variable is the BHAR calculated for each sample firm over a specific event window. As to the independent variables, in the basic model, I controlled several firm-specific, industry-specific and market-specific factors that have been commonly identified to potentially affect firm's stock returns (Girotra *et al.*, 2007; Hendricks and Singhal, 2008; Qian and Zhu, 2017; Thirumalai and Sinha, 2011). I also included dummy variables of the publication year because the adoption timing might also affect the benefits gained from the adoption (Paulraj and de Jong, 2011; Jacobs *et al.*, 2015; Xia and Zhang, 2010). I then gradually added three environmental factors to show whether each factor would explain a significant portion of BHAR variations.

4.3 Results

4.3.1 Event study results

Table 4.3 Buy-and-hold returns of sample firms and industry-size-matched control firms

Start Month	End Month	No. of observations	BHAR mean	t-statistic	p-value	BHAR median	z-statistic	p-value	BHAR positive	z-statistic	p-value
-24	-1	184	-31.26%	-1.78*	0.08	-4.52%	0.85	0.39	46%	0.96	0.34
-24	-13	184	-7.87%	-1.92*	0.06	-0.80%	0.68	0.49	49%	0.07	0.94
-12	-1	192	-6.51%	-1.36	0.18	2.55%	0.17	0.86	55%	1.23	0.22
0	0	198	0.05%	0.07	0.95	0.27%	0.03	0.97	51%	0.07	0.94
1	6	179	-1.71%	-0.79	0.43	-0.02%	0.29	0.77	49%	0.15	0.88
7	12	145	3.36%	1.52	0.13	2.80%	1.41	0.16	56%	1.33	0.18
1	12	145	3.28%	0.99	0.32	2.76%	1.42	0.16	59%	2.16**	0.03
13	18	120	3.22%	1.33	0.19	3.30%	2.04**	0.04	61%	2.29**	0.02
1	18	120	8.27%	1.61	0.11	9.30%	2.44**	0.01	61%	2.29**	0.02
1	24	94	14.56%	2.16**	0.03	18.45%	2.90***	0.00	63%	2.38**	0.02

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively (two-tailed tests).

The paired differences in BHR between sample firms that implemented 3DP and three control groups are tested over the pre-implementation, implementation, and post-implementation periods. Table 4.3 presents the results of BHAR between sample firms and industry-size-matched control firms. The results show that the BHAR over three multi-month periods (i.e. month (-24, -1), (-24, -13), (-12, -1)) prior to the implementation are generally insignificant. To examine whether the implementation of 3DP has lagged or persistent effect on firm's long-term stock returns, I further tested the significance of BHARs over the entire implementation and post-implementation period. In different time periods within month (1, 12), the BHARs are generally insignificantly different from zero, except that the percentage positive values of BHAR is 59% in month (1, 12) and is significantly higher than 50% at the 5% level. However, for longer time periods including the post-implementation periods of month (13, 24), there are significant positive changes in BHARs. Although the mean BHARs are not significantly different from zero, the non-parametric test statistics consistently show positive significant abnormal changes. The median BHARs over month (13, 18), (1, 18) and (1, 24) are 3.3%, 9.3% and 18.45%, with the significance level of 5%, 5% and 1%, respectively. More than 60% of the sample firms increase the BHR after the implementation, and is significantly higher than 50%. On average, the mean BHAR of sample firms is 14.56% and significant at the 5% level from the 1 month to 24 months after the implementation.

Table 4.4 Buy-and-hold returns of sample firms and industry-MTB-matched control firms

Start Month	End Month	No. of observations	BHAR mean	t-statistic	p-value	BHAR median	z-statistic	p-value	BHAR positive	z-statistic	p-value
-24	-1	161	-21.84%	-1.10	0.27	2.08%	0.70	0.49	50%	0.00	1.00
-24	-13	162	-2.74%	-0.56	0.57	5.18%	0.73	0.47	53%	0.71	0.48
-12	-1	179	-6.99%	-1.36	0.18	-3.73%	0.76	0.45	47%	0.60	0.55
0	0	192	0.20%	0.21	0.83	-0.22%	0.19	0.85	49%	0.07	0.94
1	6	171	1.17%	0.40	0.69	4.98%	1.70*	0.09	57%	1.84*	0.07
7	12	135	3.17%	0.94	0.35	4.64%	1.85*	0.06	55%	1.03	0.30
1	12	135	6.27%	1.38	0.17	3.06%	1.82*	0.07	56%	1.38	0.17
13	18	112	8.98%	3.42***	0.00	9.34%	3.64***	0.00	66%	3.33***	0.00
1	18	112	14.64%	2.24**	0.03	12.09%	2.91***	0.00	63%	2.56**	0.01
1	24	88	20.73%	1.98*	0.05	24.48%	2.91***	0.00	66%	2.90***	0.00

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively (two-tailed tests).

Table 4.5 Buy-and-hold returns of sample firms and Industry-Size-MTB-matched control firms

Start Month	End Month	No. of observations	BHAR mean	t-statistic	p-value	BHAR median	z-statistic	p-value	BHAR positive	z-statistic	p-value
-24	-1	176	-27.14%	-1.48	0.14	3.24%	0.15	0.88	52%	0.53	0.60
-24	-13	177	-7.52%	-1.70*	0.09	-1.41%	0.54	0.59	49%	0.15	0.88
-12	-1	189	-3.12%	-0.72	0.47	1.96%	0.07	0.94	52%	0.44	0.66
0	0	198	0.14%	0.15	0.88	-0.22%	0.08	0.94	49%	0.21	0.83
1	6	182	-1.57%	-0.63	0.53	2.00%	0.31	0.76	52%	0.37	0.71
7	12	146	1.83%	0.88	0.38	-0.05%	0.46	0.65	50%	0.00	1.00
1	12	146	0.13%	0.03	0.97	2.35%	0.36	0.72	53%	0.58	0.56
13	18	121	7.74%	3.21***	0.00	5.24%	2.89***	0.00	62%	2.56**	0.01
1	18	121	9.54%	1.99**	0.05	7.17%	1.73*	0.08	58%	1.64	0.10
1	24	93	20.26%	2.47**	0.02	17.35%	2.61***	0.01	65%	2.71**	0.01

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively (two-tailed tests).

Similar conclusions can be reached with industry-MTB-matched and industry-size-MTB-matched control groups. The results of BHAR calculated with the two matching approaches are reported in Table 4.4 and 4.5. The results show that in three multi-month periods prior to the implementation, there are generally no significant abnormal changes as indicated by both parametric and non-parametric test statistics. For BHAR over the entire implementation and post-implementation period, similar patterns are observed when industry-size-matched control groups are used as the benchmark. There are generally significant positive abnormal returns of sample firms over month (13, 18), (1, 18) and (1, 24). The mean (median) BHARs for the industry-MTB matched group over month (13, 18), (1, 18) and (1, 24) are 8.98% (9.34%), 14.64% (12.09%) and 20.73%(24.48%) respectively and are all significantly different from zero. Similar results are observed in the industry-size-MTB control group. Except for the industry-size-MTB-matched control group over month (1, 18), more than 60% of the sample firms have significantly above normal BHR over month (13, 18), (1, 18) and (1, 24).

Overall, the results of BHAR calculated with three different matching approaches generally reveal consistent patterns. Specifically, I find strong evidence that there are positive BHARs after the implementation of 3DP, and they are largely driven by the positive abnormal returns in the second year after the announcement. The market reaction to the information inherent in the implementation of 3DP persists for a relatively long time of at least 2 years after the announcement. Therefore, H1 is supported.

4.3.2 Cross-sectional analysis results

Table 4.6 Descriptive statistics and correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12
1. BHAR(%)	1											
2. Firm Size	0.20**	1										
3. MTB ratio	0.02	0.05	1									
4. R&D intensity	0.01	-0.17*	-0.06	1								
5. Prior performance	-0.04	0.27***	0.09	-0.23**	1							
6. Capital structure	0.03	0.30***	-0.14	0.38***	-0.17*	1						
7. Momentum	0.05	0.08	-0.05	0.00	-0.10	0.00	1					
8. Velocity	-0.20**	0.10	-0.07	-0.03	0.37***	-0.19**	0.03	1				
9. Type	-0.10	-0.11	-0.19**	0.05	-0.05	0.27***	-0.05	-0.42***	1			
10. Munificence	0.33***	0.03	0.25***	0.03	0.04	-0.25***	-0.09	-0.09	-0.01	1		
11. Dynamism	0.08	-0.24***	-0.04	-0.08	-0.08	-0.05	-0.18*	-0.21**	0.05	-0.08	1	
12. Competition	-0.29***	-0.22**	-0.13	0.09*	0.16	-0.14	-0.03	0.51***	-0.20**	-0.20**	0.32***	1
Mean	0.08	10.14	5.05	0.23	0.04	1.03	-0.03	0.26	0.71	0.01	0.01	0.74
Std dev	0.56	1.87	6.78	1.92	0.07	0.97	0.32	0.44	0.46	0.04	0.01	0.24

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively (two-tailed tests).

Table 4.6 presents the correlations between dependent and independent variables to be included in the regression analysis and their descriptive characteristics. For brevity in presenting and discussing the results, the regression analysis with the dependent variable of BHAR over month (1, 18) calculated with the industry-size-matched group is shown in Table 4.7.

Table 4.7 Regression results

Independent variables	Model 1		Model 2		Model 3		Model 4	
	Estimated Coefficients	$\sqrt{VIF}$	Estimated Coefficients	$\sqrt{VIF}$	Estimated Coefficients	$\sqrt{VIF}$	Estimated Coefficients	$\sqrt{VIF}$
Intercept	0.67 (0.96)		0.68 (1.03)		0.51 (0.78)		1.11 (1.62)	
Control variables								
Firm size	0.09 (2.76)***	1.14	0.07 (2.13)**	1.14	0.09 (2.61)**	1.16	0.07 (2.05)**	1.18
MTB ratio	- 0.01 (-0.71)	1.04	-0.01 (-1.41)	1.05	-0.01 (-1.25)	1.05	-0.01 (-1.17)	1.05
R&D intensity	0.03 (0.84)	1.09	0.00 (0.14)	1.10	0.01 (0.37)	1.11	0.02 (0.79)	1.11
Prior performance	- 0.03 (-0.03)	1.14	0.00 (0.06)	1.14	0.15 (0.17)	1.14	0.26 (0.30)	1.14
Capital structure	- 0.07 (-0.98)	1.19	0.00 (0.06)	1.22	0.01 (0.13)	1.22	0.00 (0.03)	1.22
Momentum	0.16 (0.87)	1.09	0.22 (1.26)	1.09	0.32 (1.85)*	1.11	0.36 (2.12)**	1.11
Velocity	- 0.52 (-3.64)***	1.13	-0.45 (-3.33)***	1.13	-0.41 (-3.04)***	1.14	-0.20 (-1.26)	1.25
Type	-0.31 (-2.27)**	1.13	-0.34 (-2.55)**	1.03	-0.34 (-2.64)***	1.13	-0.33 (-2.60)**	1.13
Announcement year	Included	1.03	Included	1.07	Included	1.04	Included	1.04
Explanatory variables								
Munificence			4.06 (3.40) ***	1.07	4.20 (3.60) ***	1.07	3.80 (3.29)***	1.08
Dynamism					17.05 (2.46)**	1.09	24.88 (3.28)***	1.15
Competition							-0.68 (-2.31)**	1.23
No. of observations	119		119		119		119	
R-squared	21.49%		29.48%		33.47%		36.85%	
Adjusted *R*-squared	10.05%		18.41%		22.27%		25.49%	
F-statistic	1.88**		2.66***		2.99***		3.24***	
ΔR-squared			7.99%		4.00%		3.38%	
ΔF			12.65***		6.33**		5.35**	

The dependent variable is the buy-and-hold returns among industry-size matched group with an event window of (1, 18).
*** and ** indicate significance at the 1% and 5%levels, respectively (two-tailed tests).

Table 4.7 presents the results for the regressions of the BHAR on control variables and three environmental factors. In model 1, the BHAR is regressed on a variety of control variables. In model 2-4, industry munificence, industry dynamism, and industry competition were gradually included in the model. The value of *R*-squared increases with additional variables adding to the regression, showing that each environmental factor explains a significant amount of the variations in the BHAR. Specifically, the coefficient of industry munificence is 4.06 (significant at the 1% level) in model 2 and it remains positive with the significance level of 1% in model 2 to 4. The result suggests that for the firms in the industry with higher level of munificence, the stock returns of 3DP implementation is more positive, supporting H2. The coefficient of industry dynamism is 17.05 in model 3 with the significance level of 5%. It remains positive with higher significance levels of 1% in model 4, indicating that the stock returns are higher for firms operating in more dynamic environment. Therefore, H3 is supported. The coefficient for industry competition is -0.68 in model 4, significant at the 5% level. The results suggest that for firms operating in more competitive industry, they will be less beneficial from the implementation of 3DP, supporting H4. Overall, my hypotheses about the moderating effect of environmental factors are supported. Specifically, industry munificence and dynamism are shown to be positively associated with the stock returns of 3DP implementations, while the industry competition is negatively associated.

4.3.3 Sensitivity analysis

I conduct several sensitivity analyses to check the robustness of my findings and to account for alternative explanations.

Propensity score matching (PSM). I employ the PSM approach to match each sample firm with a control firm that had a similar probability or propensity as the sample firm to implement 3DP but eventually did not implement 3DP. This matching approach enables us to control for other factors that may influence 3DP implementation and address possible self-selection bias (Austin, 2011; Ding *et al*., 2018). To implement PSM, I first construct a logistic regression model with 3DP implementation as dependent variable while independent variables include industry dummies, firm size, MTB ratio, return on asset, R&D intensity, industry velocity, industry munificence, industry dynamism, and industry competition. After running the logistic regression, the firms in the benchmark pool with the closest propensity scores to the sample firms are chosen as the control firms. The resulting BHARs based on the PSM approach shown in Table 4.8 reveal a consistent pattern as that found in the main analyses.

Table 4.8 Buy-and-hold abnormal returns of sample firms based on PSM

Start Month	End Month	No. of observations	BHAR mean	p-value (*t*-test)	BHAR median	p-value (WSR)	BHAR positive	p-value (sign test)
-24	-1	158	-0.48%	0.915	-1.77%	0.942	48%	0.691
-24	-13	158	3.84%	0.259	2.71%	0.241	53%	0.474
-12	-1	170	-6.60%	0.085	-3.60%	0.325	44%	0.145
0	0	174	1.24%	0.072	0.37%	0.228	51%	0.820
1	6	172	0.82%	0.692	0.96%	0.447	53%	0.402
7	12	171	0.38%	0.861	1.61%	0.536	54%	0.359
1	12	171	2.34%	0.405	5.64%	0.218	60%	0.014*
13	18	156	2.06%	0.328	2.57%	0.235	55%	0.230
1	18	156	7.40%	0.059	10.32%	0.015*	63%	0.002**
1	24	128	8.58%	0.107	9.97%	0.017*	61%	0.017*

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively (two-tailed tests; significance is adjusted using Benjamini and Hochberg's (1995) approach).

Reduced sample size. The results shown in Table 4.3 suggest that the sample size drops significantly for longer event windows because about 45% of the announcements were made in 2016 and 2017. To check whether the decrease in sample size leads to biased estimation, I follow De Jong *et al.* (2014) and calculate BHARs for the reduced sample across all event windows. I focus on the subgroup of firms that have monthly stock return data over the longest time period of month (1, 24). The BHARs of this subsample generally follow a similar pattern as those of the firms in the full sample, as shown in Table 4.9. Specifically, the BHARs over three multi-month periods (i.e., month (-24, -1), (-24, -13), (-12, -1)) prior to the implementation are not significant ($p > 0.1$). However, over the post-implementation periods, especially for month (13, 18), (1, 18) and (1, 24), I find significant positive BHARs across all three matching approaches. Additionally, the results show that this subsample enjoys greater gains in BHARs and earlier in time (e.g., month (7, 12), (1, 12)) compared with the full sample. One possible explanation is that these firms are early 3DP adopters, thus achieving greater benefits due to the first-mover advantage (Hendricks *et al.*, 2007).

Table 4.9 Buy-and-hold abnormal returns of subsample firms

Start Month	End Month	No. of observations	BHAR mean	p-value (*t*-test)	BHAR median	p-value (WSR)	BHAR positive	p-value (sign test)
Industry-size-matched control firms								
-24	-1	88	-49.43%	0.164	-0.83%	0.631	50%	1.000
-24	-13	88	-12.42%	0.091	4.97%	0.590	53%	0.594
-12	-1	92	-11.81%	0.159	4.76%	0.970	57%	0.251
0	0	94	-0.27%	0.794	-0.58%	0.502	45%	0.353
1	6	94	1.14%	0.625	3.40%	0.907	53%	0.606
7	12	94	5.63%	0.028	3.90%	0.040*	61%	0.049*
1	12	94	6.56%	0.091	6.06%	0.025*	63%	0.017**
13	18	94	5.21%	0.052	4.30%	0.009**	65%	0.005**
1	18	94	12.28%	0.029	12.24%	0.001***	64%	0.010**
1	24	94	14.56%	0.033	18.45%	0.004**	63%	0.017**
Industry-MTB-matched control firms								
-24	-1	78	-42.66%	0.290	2.55%	0.511	50%	1.000
-24	-13	79	-6.56%	0.434	10.03%	0.413	56%	0.368
-12	-1	84	-7.52%	0.352	-2.13%	0.648	49%	0.913
0	0	90	0.67%	0.642	0.44%	0.615	51%	0.916
1	6	90	4.13%	0.276	5.19%	0.039*	59%	0.113
7	12	89	5.58%	0.086	4.64%	0.046*	56%	0.289
1	12	89	9.01%	0.096	6.07%	0.017**	61%	0.056
13	18	88	12.49%	0.000***	12.68%	0.000***	69%	0.000***
1	18	88	18.55%	0.014*	15.16%	0.000***	67%	0.002***
1	24	88	20.73%	0.051	24.48%	0.004**	66%	0.004**
Industry-size-MTB-matched control firms								
-24	-1	85	-45.74%	0.218	4.67%	0.661	53%	0.665
-24	-13	86	-7.92%	0.336	8.39%	0.633	57%	0.235
-12	-1	93	-9.44%	0.216	-2.08%	0.462	47%	0.679
0	0	96	1.18%	0.305	-0.22%	0.727	49%	0.919
1	6	96	-1.44%	0.671	-0.67%	0.946	48%	0.760
7	12	95	3.10%	0.246	1.64%	0.345	52%	0.838
1	12	95	1.59%	0.741	2.32%	0.493	53%	0.682
13	18	94	11.01%	0.000***	10.31%	0.000***	67%	0.001**
1	18	94	13.49%	0.010*	9.16%	0.020*	60%	0.079
1	24	93	20.26%	0.015*	17.35%	0.009**	65%	0.007**

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively (two-tailed tests; significance is adjusted using Benjamini and Hochberg's (1995) approach).

Alternative dependent variable. I also examine whether the results of regression analysis are consistent if BHAR with alternative event window and benchmark is used as the dependent variable. Table 4.10 presents the regression results with the BHAR calculated over month (1, 24) and with industry-MTB-matched and industry-size-MTB-matched benchmark groups. The coefficients of the three environmental factors are significant and consistent across different regression models, demonstrating the robustness of the regression results.

Table 4.10 Sensitivity analysis within different event windows and benchmark groups

Models	Munificence	Dynamism	Competition	N	R-squared	F-statistic
Industry-size-matched group; Event window = (1, 24)	3.49 (2.07)**	19.25 (1.70)*	-0.91 (-2.39)**	93	36.17%	2.33***
Industry-MTB-matched group; Event window = (1, 18)	3.99 (2.80)***	28.57 (3.02)***	-0.75 (-2.06)**	109	35.15%	3.12***
Industry-Size-MTB-matched group; Event window = (1, 18)	4.69 (4.23)***	11.75 (1.67)*	-0.64 (-2.25)**	120	31.73%	2.62***

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively (two-tailed tests)

4.4 Conclusion and Discussions

This research quantified the effect of 3DP implementation in terms of stock returns. Based on 232 announcements of 3DP implementation made by U.S.-listed firms from 2010 to 2017, I employed the event study method to examine the stock returns of 3DP implementation over two years after the implementation. Analysis results show significant higher BHARs of sample firms compared with their non-implementation industry peers over the two-year post-implementation period. The mean BHARs range from 15% to 21%, comparable to the BHARs observed in other event studies of some management techniques such as Total Quality Management (38% to 46% over five-year post-implementation period) (Hendricks and Singhal, 2001), Enterprise Resource Planning (11% over three-year post-implementation period) (Hendricks *et al.*, 2007), and Supply Chain Management systems (18% over three-year post-implementation period) (Hendricks *et al.*, 2007). Similar magnitude of BHARs indicates that the expected business value of 3DP implementation is comparable to that of those well-established management techniques in the manufacturing process. Therefore, the results highlight the importance of strategic response to 3DP which could substantially influence firm performance.

From the contingency perspective (Anand and Ward, 2009; Benito-Osorio *et al.*, 2012; Pagell and Krause, 2004), the study further investigates how the environmental factors affect benefits of broadening operational scope through 3DP implementation. Specifically, the regression analyses generally show that the stock returns due to the implementation of 3DP are contingent on the industry environments. The results confirmed the hypotheses that the benefits of 3DP increase with the level of industry munificence and dynamism (H2 and H3), but decrease with the level of industry competition (H4). While the alignment between environment and manufacturing capabilities has long been stressed in literature, most previous studies have depicted manufacturing capabilities as the adaptation to different environmental conditions (Anand and Ward, 2009; Pagell and Krause, 2004; Terjesen *et al.*, 2011). My study extends this stream of literature by emphasizing the moderating role of environmental factors in affecting stock returns of 3DP implementation. The empirical investigation of environmental conditions facilitates practitioners to identify appropriate technologies and applications that fit in their specific industry environment.

Consistent with my prediction, the implementation of 3DP will generate higher abnormal returns for the firms in more munificent industries. I attribute the greater benefits to easier access to the resources which would support the effective implementation of 3DP. A Delphi survey conducted by Thomas-Seale *et al.* (2018) identified critical barriers which limit broader applications of 3DP, including "education, cost, software, material, mechanical properties, validation and finishing". Specifically, since many applications of 3DP are still in research and development stage, current trainings of 3DP only provide an overview of the technology, without in-depth understanding or hands-on experience. Additionally, the subtractive nature of CAD software sometimes contradicts with the nature of additive manufacturing, and it is not sufficiently advanced to exploit certain features that could be manufactured (Thomas-Seale *et al.*, 2018). Therefore, the results suggest that in more munificent industries, firms are believed to be more likely to obtain resources such as government funds, labor markets, material suppliers, software vendors, which are critical to support the implementation of 3DP.

As hypothesized, the study demonstrates that firms gain greater value in 3DP implementation in more dynamic industries, justifying the alignment between technological features and environmental requirement (Anand and Ward, 2009; Stoel and Muhanna, 2009). A long-established contingency framework illustrates that the optimal manufacturing technology should be determined by the demand of specific environments (Grant *et al.*, 1991; Venkatraman, 1989). My results empirically show that 3DP excels at increasing production flexibility to meet fluctuating demands both time-efficiently and cost-effectively, thus making it more likely to be a source of competitive advantage in dynamic industries. For instance, the apparel industry is notable for fast-changing nature of fashion and highly volatile customer preferences. With the implementation of 3DP, Nike successfully slashed the time required for manufacturing and testing and better accommodates the ever-changing fashion (Jopson, 2013). On the contrary, in industries characterized as stable demand and standardized products, the value of increasing flexibility is less obvious.

I proposed that the level of industry competition is negatively associated with the abnormal returns due to 3DP implementation. My results indicate that competitive advantage due to 3DP implementation is more salient in less competitive industries. A plausible explanation proposed by Weller *et al.* (2015) is that 3DP allows monopolists to charge a price premium by offering customized products or services. By contrast, in competitive markets, 3DP lowers the market entry barrier and enables firms to service multiple segments because it is much simpler and less costly to set up the production system with 3DP technology. 3DP ultimately leads to intensified competition and decreased market prices in competitive markets. To sum, the results demonstrate the effectiveness of 3DP in spurring competition, rather than deterring potential market entrants in competitive markets. With technology diffusion and intensified competition, early-mover advantage of 3DP is likely to diminish in competitive markets.

The present study also has some limitations. First, due to data limitations, I am not able to observe the effect of 3DP implementation on firms' operating performance over long time periods. It would be interesting to investigate whether the increased stock returns is synchronized with improved operating performance. Moreover, the sample may be biased toward large firms. The reason for the bias could be that only large firms have the slack resources to initiate the pioneering 3DP business. Nevertheless, the event study method enabled us to match firms implementing 3DP with their industry peers without 3DP implementation but with similar sizes, helping reduce this possible bias.

Chapter 5 Conclusions and implications

The first study reviews 29 short-term event studies published in renowned OSCM journals between 1995 and 2017, and concludes the following observations: (1) The majority of the short-term event studies in OSCM focus on internal corporate events in the U.S. context. (2) While most studies set standard event windows including at most three days around the event, theoretical justifications are not commonly provided for short-term event studies with longer event windows. (3) Researchers often rely on multiple data sources to identify the events under study, but pay less attention to the issue of confounding events. (4) The market model is the most popular estimation model in the OSCM literature, but some researchers also employ multiple estimation models to increase the robustness of the analysis. (5) Researchers are wary of possible violations of the assumptions for the significance test, so adopting various modifications of the traditional *t*-test according to different research contexts. (6) Researchers often conduct subsequent cross-sectional regression and ANOVA to probe into the operational determinants of variations in abnormal returns.

Based on my analysis, I provide several recommendations for future event studies in OSCM. First, I urge OSCM researchers to take advantage of events external to the firms concerned and occurring outside the U.S. context, advancing our understanding of the financial impacts of these under-studied events. Second, researchers should be careful about expanding the event windows, and provide theoretical explanations to justify the window lengths. Third, removing confounding effect is a critical step in conducting short-term event studies. Fourth, the possible self-selection bias should not be ignored, especially when the events under study are initiated by firms voluntarily. Fifth, employing alternative models to estimate the expected returns could enhance the robustness of the analysis. Sixth, modifications of the traditional *t*-test might become necessary in some research settings such as external events and industry-specific studies. Finally, independence is a vital assumption in testing the significance of cumulative abnormal returns. It thus is important to address the issues arising from time and industry clustering.

In the second study, I conduct a short-term event study and find that the earthquakes have a negative impact on the stock returns of the semiconductor manufacturers located in China, suggesting that the contagion effect overweighs the competitive effect. Moreover, the negative impact is more pronounced for firms with supply chain linkages with Japanese firms, confirming the contagion effect via interfirm linkages. However, I also find a positive impact among Chinese firms with high inventory turnover and customer concentration, supporting the operational efficiency perspective which suggests that firms with higher operational efficiency (higher inventory turnover and higher customer concentration) are able to gain competitive advantage and reap more benefits from the misfortune of their overseas competitors. Overall, the research reveals the dynamic effects of a natural disaster across national borders, providing important implications for global supply chain management and competition.

The second study provides important implications about supply chain risks and competitive advantage for firms competing in a global scale. Existing event studies concentrate on internal operational glitches and supply chain disruptions. This study calls for more attention on the impact of external events, especially in global supply chains where firms are more closely connected and are increasingly vulnerable to disruptions (Manuj and Mentzer, 2008). My study provides empirical evidences in favor of the supply chain linkage as a disruption transmission mechanism proposed by Carvalho *et al*. (2016). This study also indicates that, irrespective of supply chain linkages, most of the firms within the same industry can hardly isolate themselves and preserve their own interests facing industry-specific disasters in the global market. Conservative investors could be wary of greater uncertainties in future profitability resulted from the natural disasters and react negatively to the information. Disruptions which occur anywhere in the network may create a widespread impact. Therefore, compared with firms with domestic supply chains, firms with global supply chains encounter greater uncertainties and risks and are more prone to external disasters across national borders.

Additionally, the second study also provides implications for firms to gain competitive advantage in the global competition. Previous studies generally reveal a negative impact of catastrophic disasters on the performance of disaster-stricken firms or their supply chain partners. However, positive competitive effect is less discussed in the OM context. For example, Park *et al*. (2013) conducted case studies of major Japanese manufacturers which experienced supply chain disruptions after the 2011 Japanese earthquake and tsunami. My study reveals dynamic effects within the industry across national borders based on the concepts of contagion and competitive effect in accounting and finance. In particular, the results show that firms in the global supply chain encounter greater opportunities to gain competitive advantage. From the operational efficiency perspective, this study indicates that firms with the higher efficiency (i.e. higher inventory turnover and higher customer concentration) can reap the benefits from the difficulties experienced by their overseas industry peers.

In the third study, I conduct a long-term event study based on 232 announcements of 3DP implementation made by U.S. public-listed firms between 2010 and 2017. The event study results suggest that firms implementing 3DP enjoy significant higher stock returns compared with their non-implementation industry peers over two years after the implementation. This finding is consistent with the operational perspective which argues that 3DP enables firms to broaden their operational scopes, resulting in positive stock returns. However, it is less likely that firms operating in different environments will gain the same benefits from their 3DP implementation. For example, while 3DP may enable firms operating in dynamic environments to gain a competitive advantage due to its ability to broaden the firms' operational scopes to satisfy the changing customer preferences and fluctuating market demand in such environments (Dess and Beard, 1984; Jansen *et al.*, 2006), firms operating in less munificent environments may not have sufficient resources and support to implement 3DP to broaden their operational scopes, thus preventing them from reaping the benefits of 3DP innovation (Lester *et al.*, 2005; Park and Mezias, 2005). Therefore, the research further considers how the stock returns due to 3DP implementation vary across firms operating in different environments. The cross-sectional regression analysis shows that the stock returns due to 3DP implementation are more pronounced for firms operating in more munificent, more dynamic, and less competitive industry environments. These findings highlight the importance of the fit between 3DP-enhanced operational scopes and firms' operating environments.

The third study makes important contributions to both research and managerial practice in several ways. First, this study is one of the first research efforts that provide empirical evidence of the performance impact of 3DP in terms of abnormal stock returns. Existing studies of 3DP have primarily discussed its theoretical implications from different perspectives (Huang et al., 2012; Petrick and Simpson, 2013; Weller et al., 2015; Jiang et al., 2017; Khorram Niaki and Nonino, 2017), with very few having empirically examined these implications commonly assumed in literature. Employing an event study method, the study demonstrates that the implementation of 3DP generates positive abnormal stock returns in the long term, supporting the broadening operational scope arguments. Additionally, I believe that the quantitative investigation of stock returns is important from a managerial standpoint. When a technology such as 3DP potentially forms the basis for a firm's future growth and profitability, it is important for practitioners to verify the value inherent in the implementation of the technology. Although 3DP has received extensive public attention in recent years, the current level of adoption of the technology is still relatively low. The low adoption rate is partly due to practitioners' lack of the knowledge of 3DP and difficulties to quantify its impact (Ernst & Young, 2016). Therefore, the study would help practitioners to understand the business value of 3DP and made strategic decisions.

Second, the third study sheds some light on the research on manufacturing capabilities by indicating that the value of manufacturing capabilities is contingent on environments in which the capabilities are employed. Most previous research of manufacturing capabilities is built on the "structure-conduct-performance" framework (Terjesen *et al.*, 2011), meaning that different environmental conditions lead to the development of appropriate capabilities. Less research has focused on the moderating role of environmental conditions in the relationship between manufacturing capabilities and performance. The study advances the understanding of the performance implications of manufacturing capabilities from the perspectives of environmental support and environmental requirement. My findings also suggest that the environmental conditions in which the firms operate may facilitate practitioners to identify the suitable technology that would enable firms to obtain financial capital to sustain their future growth and development. This study corroborates the importance of environmental conditions in assessing the value of investments in manufacturing capabilities.

Third, the third study shows that the fit between operational scope strategies and specific environmental conditions is important in achieving improved firm performance. Previous studies generally show that the association between broadening operational scope and firm performance is inconclusive and environmental-dependent (Benito-Osorio *et al.*, 2012), while fewer studies have empirically demonstrated the value of the fit between operational scope strategies and the environment (Anand and Ward, 2009). This study extends this stream of literature by leveraging the empirical context of 3DP implementation to justify the argument that the effectiveness of broadening operational scope is dependent on industry environmental conditions. I point out that the match between operational scope strategy and environment will affect the effectiveness of the specific operational scope strategy.

Appendix 3D printing implementation sample announcements

Table 3D printing implementation sample announcements

Firm	Announcement headline	Announcement main content	Industry
Amazon.com Inc	Amazon offers 3D printing to customize earrings, bobble head toys	SAN FRANCISCO, July 28 (Reuters) - Amazon.com Inc will offer 3D printing services that allow customers to customize and build earrings, bobble head toys and other items from third-party sellers using a new personalization option on its website. Most of the more than 200 items available on the company's new 3D printed products store, which launched on Monday, can be customized using a new feature that allows users to rotate and change the item they are viewing.	Catalog and Mail-Order Houses (SIC:5961)
United Parcel Service	The UPS Store Makes 3D Printing Accessible to Start-Ups and Small Business Owners	The UPS Store(R) today announced it is the first nationwide retailer to test 3D printing services in-store. Select UPS Store locations will be offering the services to start-ups, small businesses and retail customers, beginning in the San Diego area with locations in additional cities across the United States in the near future. The UPS Store locations will be equipped to produce items like engineering parts, functional prototypes, acting props, architectural models, fixtures for cameras, lights and cables. In addition, The UPS Store locations offer a range of services tailored to meet the needs of small businesses in all stages of the business lifecycle. Not only can small business owners receive well-recognized services like packing and shipping, printing, faxing, direct mail and mailbox services, but The UPS Store locations also will work with business owners to develop custom solutions to meet their unique business needs.	Courier Services, except by Air (SIC: 4215)
Ford Motor	Ford begins large-scale 3D printing trial	US automotive manufacturer Company this week announced plans to begin testing the production of large-scale parts using 3D printing. To do this, Ford is partnering with Stratasys, one of the USs largest 3D printing manufacturers. Ford will use a Stratasys Infinite Build 3D-printer in order to print a large number of parts, some more than a meter in size.	Motor Vehicle Parts and Accessories (SIC: 3714)

Firm	Announcement headline	Announcement main content	Industry
Under Armour	Under Armour's 3D-printed shoes bring computer designer to heel	3D printing is being increasingly adopted by sportswear companies as a means of producing shoes that are lighter and custom molded for a snug fit. Like Nike, Adidas and New Balance before it, Under Armour has now launched a new trainer produced with the help of 3D printing technology. But the use of advanced technology doesn't stop there, with the shoe's latticed midsole dreamt up not by one of the company's designers, but by some pretty imaginative computer software instead. Under Armour's new Architect multipurpose trainers are aimed at athletes taking part in a range of exercises, with the intention of saving them the trouble of switching shoes. So to come up with shoe design that would provide cushioning and support through different workouts, Under Armour enlisted the help of Autodesk's generative design software, Autodesk Within.	Sporting and Athletic Goods (SIC:3949)
Sirona dental systems	Sirona Dental Systems Validate and Approve Objet to Offer Complete Dental Model Production to Their Worldwide Resellers and Dental Lab Customers	BENSHEIM, Germany and REHOVOT, Israel, Feb. 21, 2012 /PRNewswire/ -- Sirona (Nasdaq:SIRO), the dental technology leader, today announced its latest collaboration with Objet Ltd. (Rehovot, Israel), the innovation leader in 3D printing for rapid prototyping and additive manufacturing. Sirona has approved Objet's 3D Printing Systems for the manufacture of custom printed dental models. The approval is a milestone in Objet and Sirona's long term relationship. Sirona's worldwide reseller partners and their dental lab customers will now be able to benefit from Objet's ultra-thin layer, high resolution 3D printing systems.	Medical, Dental, and Hospital Equipment and Supplies (SIC:5047)

Firm	Announcement headline	Announcement main content	Industry
Lockheed Martin Corp.	RedEye and Lockheed Martin Build One of the Largest 3D Printed Parts for Space Project	2014 MAY 14 (VerticalNews) -- By a News Reporter-Staff News Editor at Defense & Aerospace Week -- RedEye, by Stratasys (Nasdaq: SSYS), one of the world's leading service bureaus, recently partnered with Lockheed Martin's Space Systems Company (SSC) to additive manufacturing two large fuel tank simulators for a satellite form, fit and function validation test and process development. With the biggest tank measuring 15 feet long, the project marks one of the largest 3D printed parts RedEye has ever built.	Search, Detection, Navigation, Guidance, Aeronautical, and Nautical Systems and Instruments (SIC: 3812)
Schlumberger Ltd.	Global Oil and Gas firm Schlumberger achieves improved efficiencies and quality using Exception EMS’ PCA rapid prototyping service	Calne, Wiltshire - Schlumberger, the world's leading supplier of technology, integrated project management and information solutions to customers working in the oil and gas industry - is using Exception EMS' fast turnaround PCA 'On-Demand' service to improve costs, and efficiencies with rapid prototyping. Chris Kern, Surface Systems Engineer at Schlumberger commented, "Whilst we were looking to drive down costs, we needed to retain quality and increase our efficiencies for rapid prototyping of PCAs. We were struggling to turn round a prototype quickly so Exception EMS' On Demand service seemed a good fit for us." Kern was impressed with the services provided by Exception EMS and in January, 2014 the company began working together. Using Exception EMS' On-Demand service has meant that Schlumberger gets access to 24/7 availability from a technology driven manufacturing team, with enhanced flexibility to support rapid and complex PCB assembly services. Importantly, Schlumberger also gets full transparency during the quotation and fulfillment cycle.	Oil and Gas Field Services, Not Elsewhere Classified (SIC:1389)

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