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The impact of R&D investment on mitigating supply chain disruptions: Empirical evidence from U.S. firms

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A R T I C L E I N F O

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A B S T R A C T

The purpose of this paper is to examine the moderating effect of a firm's R&D investment in mitigating supply chain disruptions. We use four categories of disruption risks in a supply chain: demand, process, supply, and environmental. Building upon dynamic capability theory, we examine the relationships among a firm's R&D investment, supply chain disruption risk drivers, supply chain performance, and firm performance, using data collected from manufacturing and service organizations in the U.S. Our findings show that a firm's R&D investment can be regarded as enhancing the firm's resilience capability. R&D investment significantly mitigates the effects of process disruption, supply disruption, and demand disruption on firm performance. R&D investment significantly mitigates the effects of process disruption and environmental disruption on supply chain performance. Our study provides one of the early empirical findings of the role of a firm's investment in innovation as a means of improving the firm's resilience to supply chain disruptions.

1. Introduction

In today's turbulent and uncertain environment, every enterprise in the supply chain is vulnerable to disruption phenomena (Knemeyer et al., 2009; Ponomarov and Holcomb, 2009; Carvalho et al., 2012; Soni et al., 2014; Fiksel et al., 2015). As a result, an understanding of how firms can manage supply chain disruptions has become increasingly important for both academics and practitioners (Craighead et al., 2007; Blackhurst et al., 2011; Azadegan et al., 2019; Nooraie et al., 2019). A study conducted by the World Economic Forum and Accenture (2013) found that 80% of firms consider resilience to supply chain disruptions as a top priority. Despite the importance of supply chain resilience, few companies have reported generating returns from their investments in supply chain risk management. Thus, while managers understand the importance of supply chain risk management, the existing risk management practices do not appear to be financially viable.

To respond to supply chain disruption risks, organizations have focused on the development of supply chain resilience capabilities (Christopher, 2005; Ponomarov and Holcomb, 2009; Ambulkar et al., 2015; Shekarian et al., 2019; Nooraie et al., 2019). Organizations want the capability to be adaptive and responsive to unexpected events emerging from a firm's supply chain (Ponomarov and Holcomb, 2009; Sabatino, 2016), and organizations want to develop the capacity for resistance and recovery (Melnyk et al., 2014; Williams et al., 2017). Although resilience is important to a firm's capability to manage supply chain disruptions, there is limited research on how firms develop resilience to supply chain disruptions (Blackhurst et al., 2011; Jüttner and Maklan, 2011).

One of the capabilities contributing to a firm's resilience is innovation (Kamalahmadi and Parast, 2016; Parast et al., 2019; Sabahi and Parast, 2019). Su and Linderman (2016) showed that innovation capability is one of the four pillars of sustained high-quality performance of organizations. Investment in research and development (R&D) positively affects firm performance, where the effect is stronger for manufacturing firms compared to service organizations (Ehie and Olibe, 2010). Reinmoeller and Van Baardwijk (2005) highlighted the impact of innovation on resilience; they found that among the resilient enterprises they studied, the focus on innovation increased by 235% over 20 years. They drew a conclusion that firms could be able to respond to disruptions and adapt to rapid changes in the environment only when the firms assign enough resources to innovation. Golgeci and Ponomarov (2013) stated that resilience may be regarded as a vital dimension of a firm's continuity, and innovativeness may be regarded as one of the key enablers of resilience. In their empirical study on the impact of firm innovativeness on effective responses to supply chain disruptions, they found that both firm innovativeness and innovation magnitude are positively associated with supply chain resilience. Akgün and Keskin (2014) studied 112 firms to examine the relationship between

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organizational resilience capacity, product innovation, and firm performance. They found significant associations between resilience-capacity variables and a firm's product innovativeness, where product innovativeness mediates the relationship between a firm's resilience and its performance.

Although innovation has been viewed as a key component of a firm's long-term survival and development, the role of innovation in increasing the resilience of an enterprise has been relatively disregarded (Kamalahmadi and Parast, 2016). In fact, the idea of "Resilience: Continuous renewal of competitive advantages" (de Oliveira Teixeira and Werther, 2013, p. 333) suggests a close relationship between innovation as a sustained form of competitive advantage and organizational resilience. The importance of firm innovation as a source of competitive advantage has been discussed in both the strategy and the operations management literature: innovation creates market value (Cho and Pucik, 2005; Weerawardena and Mavondo, 2011), reduces organizational vulnerability (Markman et al., 2009), increases firm response to uncertainty (Stevens and Dimitriadis, 2004), and enables a firm to deal with volatile or lagged demand (Fisher, 1997). Thus, a culture of innovation and supporting continuous innovation is regarded as an underlying culture of resilience (de Oliveira Teixeira and Werther, 2013). Operations management scholars have called for studies that can bridge the gap between innovation and operations management (Krishnan, 2013); however, scholarly work in the interaction of operations and innovation management is limited. We aim to address this important gap in the operations management and innovation literature.

Organizational resilience can be regarded as either a static or a dynamic capability (Richtnér and Löfsten, 2014). A static view of firm resilience is concerned with the organizational capability to maintain its functions, processes, and organizational structure in a turbulent environment and during external shocks; a dynamic view of resilience deals with the capability of a firm to restore operations, regain control, and recover its former operational conditions or achieve a new (improved) operational condition (Allenby and Fink, 2005; Brede and de Vries, 2009; Schweitzer et al., 2009). In this study, we use the dynamic view of organizational resilience, which can be examined as idiosyncratic, firm-specific innovations that are the result of investment in R&D (Andergassen et al., 2015). This viewpoint on firm resilience aligns with the dynamic capabilities theory of the firm, which views resilience as a dynamic capability that grows and develops over time (Wildavsky, 1988) in order to cope positively with unexpected changes in the environment (Sutcliffe and Vogus, 2003). Thus, a firm's investment in innovation is regarded as a dynamic capability that is directly related to improving the firm's resilience (Reinmoeller and Van Baardwijk, 2005). While prior studies have examined the impact of supply chain disruption risks on firm performance (Wagner and Bode, 2008) and have examined the relationship between firm innovation and firm resilience (Golgeci and Ponomarov, 2013), it is not clear how a firm's investment in R&D can mitigate the negative impact of different sources of disruption on organizational performance. In addition, the literature has overlooked the impact of R&D investment in mitigating the negative effect of supply chain disruptions on firm performance and supply chain performance.

This study seeks to fill these gaps by examining the impact of a firm's investment in innovation on mitigating supply chain disruptions, and whether investment in innovation can help organizations to be more responsive to supply chain disruptions. This study builds on two prior studies in supply chain disruption risk and resilience: Christopher and Peck (2004) proposed a conceptual framework for supply chain resilience; and Wagner and Bode (2008) examined the effect of supply chain disruption drivers on supply chain performance. We use the resilient supply chain framework proposed by Christopher and Peck (2004) and the survey of supply chain risk management drivers developed by Wagner and Bode (2008) to examine the effect of R&D investment as an organizational resilience enhancer that mitigates the effect of various supply chain disruptions on firm performance and supply chain performance. This study also extends the study by Golgeci and Ponomarov (2013) that addressed the impact of firm innovativeness and innovation magnitude on supply chain resilience.

We contribute to the literature in supply chain risk management and innovation in two ways. First, we examine the relationship among supply chain disruption risks, investment in innovation, and firm performance, thereby providing a more nuanced explanation of how a firm's innovation can strengthen the firm's resilience to supply chain disruptions. Second, we examine the relationship among disruption risks, innovation, and supply chain performance.

The remainder of this paper is organized as follows. We first review the literature on supply chain risk and resilience. We then we provide our theoretical framework that relates innovation and a firm's resilience to supply chain disruptions, and we develop our hypotheses. Subsequently, we describe our methodology, the sample, and the estimation procedure to examine our research questions. Finally, we discuss our results, address the relevance of our findings to the theory and practice of supply chain risk management and innovation, and discuss managerial implications and future research.

2. Theoretical perspective

Our theoretical framework on the relationship between firm innovation and supply chain disruption management is built on the principles of dynamic capabilities theory (Teece, 2007). The dynamic capability of a firm is regarded as an organizational capability to resolve problems, scan opportunities, and mitigate threats through re-creation of resources and capabilities, in order to remain relevant and competitive in a turbulent environment (Barreto, 2010; Di Stefano et al., 2010). As an extension of the resource-based view of the firm, dynamic capabilities theory has a specific focus on innovation and creating value (Katkalo et al., 2010). Because value creation and the development of new capabilities are the results of the innovative activities of a firm (Teece, 2007; Ellonen et al., 2009), dynamic capabilities theory is an appropriate theoretical lens to relate firm innovation to firm resilience and organizational performance in turbulent environments.

The above discussion underlines the entrepreneurial nature of dynamic capabilities, since organizations need to continuously develop solutions to the threats and opportunities emerging from the business environment (Pitelis and Teece, 2010; Teece, 2012; Kindström et al., 2013). Since firms are heterogeneous in terms of their ability to innovate due to their levels of innovation capability (Hult et al., 2004), they exhibit different levels of innovation outcomes. It is the innovation capability of a firm that enables the firm to respond to changes in the environment, develop solutions to emerging problems, and take necessary actions. The literature shows innovative firms do a much better job in measures of customer satisfaction (Cohen et al., 2000), respond more effectively to environmental uncertainty (Stevens and Dimitriadis, 2004), and are more capable in dealing with demand volatility (Fisher, 1997). This suggests that innovative firms are more resilient.

As firms are engaged in inter-firm collaborations and supply chain partnerships, their ability to develop dynamic capabilities is essential to their success. For example, flexibility can be regarded as a firm-level capability (Uhlenbruck et al., 2003), while supply chain agility is a network-level capability (Gligor and Holcomb, 2012). Thus, dynamic capability theory, while being primarily discussed at the firm level, can be used to address performance at both the firm level and the supply chain level (Defee and Fugate, 2010; Ponomarov and Holcomb, 2009). This indicates that a firm's innovation capability can be regarded as a dynamic capability that can enhance organizational performance in unpredictable and volatile environments. This conceptualization of a firm's innovation capability aligns with the definition proposed by Lengnick-Hall and Beck (2005) and Lengnick-Hall et al. (2011), who coined the term "resilience capability" and discussed how it enables an organization to respond to disruptive events that could threaten organizational survival.

The linkage between innovation management and risk management can be further examined through understanding their relationship to change. Innovation management and risk management are both concerned with the ability of an organization to develop capabilities to be adaptive and to respond to change (Walker et al., 2006). Risk management entails development of capabilities to mitigate the negative impact of unfavorable outcomes; innovation management is concerned with activities that lead to desired (i.e., positive) outcomes. There are also differences between risk management and innovation management with respect to how organizations view them. Innovation management portrays itself as a proactive activity that aims to enhance a firm's competitive position, so it is usually related to growth (Cho and Pucik, 2005; Crossan and Apaydin, 2010). Risk management is usually regarded as reactive behaviors, intended to assess the risks of potential disruptions and ensure that the firm has plans in place to maintain and sustain the current organizational operating practices in the presence of disruptions (Bode et al., 2011). A core capability common to both resilient organizations and innovation organizations is their ability to anticipate changes in the environment and their ability to proactively learn (Bloomberg, 2014). At the conceptual level, both risk management and innovation management are concerned with change, but they deal with it in different ways.

Since innovation involves venturing into unknown territory, it requires the firm to search for opportunities and examine the potential possibilities for growth, which involves risks (Delmas, 2002). In the pursuit of innovation, firms need to reinvent their processes and make changes to their organizational norms and routines (Tushman and O'Reilly, 1996). They also need to revisit their interactions and business practices with their suppliers, customers, and stakeholders, to ensure that they have the capabilities in their innovation ecosystem to support their innovation programs. The dynamic capability of a firm would be able to explain the heterogeneity in firm performance during disruptions and turbulent environments (Dierickx and Cool, 1989; Teece et al., 1997). Organizational capabilities are the main driver of generating valuable outcomes through integrating various organizational resources (Helfat and Peteraf, 2003; Winter 2003). A firm's investment in R&D can be regarded as an organizational capability that could explain differences in firm performance during disruptions.

Therefore, organizational investment in innovation can be regarded as a dynamic capability that enhances a firm's response to supply chain disruptions and maintains the firm's competitive position in responding to change in the firm's business environment. In a supply chain environment, a firm is exposed to different types of disruption risks (supply risk, demand risk, environment risk, and process risk), so it is expected that the magnitude of the impact of a firm's innovation capability on mitigating supply chain disruptions would vary. In other words, the impact of a firm's innovation capability as a resilience enhancer varies based on the source of disruption in the supply chain. We discuss this further in the following section.

3. Risk and resilience in supply chains

Research in supply chain management has received considerable attention by both academics and practitioners, primarily as a result of increased vulnerability to disruption in supply chains due to external shocks and operating in a more turbulent environment (Kamalahmadi and Parast, 2016). Supply chain risk management (SCRM) is defined as "the identification of potential sources of risk and implementation of appropriate strategies through a coordinated approach among supply chain risk members, to reduce supply chain vulnerability" (Jüttner et al., 2003, p. 201). In order to remain competitive and mitigate supply chain disruptions, firms have emphasized the development of resilience enhancers, i.e., organizational capabilities that can enhance their responsiveness to supply chain disruptions. Thus, a firm's resilience to supply chain disruption can be viewed as a dynamic capability that enhances the firm's performance during times of crisis and when facing an unpredictable environment (Blome et al., 2013; Gu and Huo, 2017).

According to Kamalahmadi and Parast (2016), supply chain risk management is concerned with the assessment of sources of risk across the supply chain and the development of strategies to deal with them. Several studies have identified practices that enhance firm performance to supply chain disruptions. One of the early studies in identifying supply chain resilience was conducted by Christopher and Peck (2004); their classification of supply chain risks is shown in Fig. 1. Their classification covers five categories: process risk, control risk, demand risk, supply risk, and environmental risk.

Prior studies have shown the negative impact of supply chain disruptions on organizational performance. Wagner and Bode (2008) examined the effect of supply chain disruption risk sources on supply chain performance. Their results show that demand risk and supply risk have significant effects on supply chain performance. Chen et al. (2013) examined the effect of collaboration on mitigating supply, demand, and process risks. Their results show that while collaboration is an effective mitigation strategy for supply chain risk management, only the mitigation of process risk and demand risk has a direct effect on supply chain performance. In another study, Golgeci and Ponomarov (2013) examined the relationships linking firm innovativeness, innovation magnitude, disruption severity, and supply chain resilience. The findings suggest that both firm innovativeness and innovation magnitude are positively associated with supply chain resilience. The importance of a firm's innovation capability as an organizational capability in mitigating supply chain disruptions was also addressed by Kamalahmadi and Parast (2016). They identified innovation as a component of organizational culture that is reflected in the organizational supply chain risk management culture. Overall, while practices such as innovation and collaboration improve organizational response to supply chain disruptions and enhance organizational resilience, the impact of these resilience enhancers on supply chain performance appears to vary based on the source of disruption.

We view supply chain resilience as a firm's dynamic capability that can help the firm respond to and recover from supply chain disruptions (Ponomarov and Holcomb, 2009; Golgeci and Ponomarov, 2013). Every organization's supply chain is subject to disruption risks (Blackhurst et al., 2005; Greening and Rutherford, 2011), which can originate from supply, process, demand, control, and environment (Christopher and Peck, 2004). Our objective in this paper is to examine the importance of firm investment in innovation as a resilience enhancer in mitigating supply chain disruptions. The management literature provides support for the relationship between supply chain resilience and innovation (Folke et al., 2002), where innovation is regarded as acting creatively to address risk (Mitroff and Alpaslan, 2003), improving the firm's resilience to external shocks and changes in the business environment and thereby maintaining the long-term survival of the firm. We use the conceptual model in Fig. 1 as the overarching framework for supply chain resilience. This enables us to examine the impact of firm innovation on mitigating different sources of disruption risks. To relate our findings to previous studies in supply chain disruption risk and organizational performance (e.g., Wagner and Bode, 2008; Chen et al., 2013), we focus on demand, supply, process, and environmental risk drivers.

4. Hypotheses

We identify a firm's investment in innovation (R&D investment) as an organizational capability that can enhance the firm's resilience to supply chain disruptions (Golgeci and Ponomarov, 2013) from multiple perspectives. First, we build our arguments from the existing literature that shows the relationship between innovation and change: innovation improves a firm's willingness to perceive change and develop action plans to deal with new organizational challenges (Azadegan and Dooley, 2010). Second, we argue that innovative firms are more inclined to develop novel ideas and solutions to cope with external shocks and unforeseen changes in the environment (Teece, 2007). The dynamic capability of the firm supports the importance of firm innovation in the

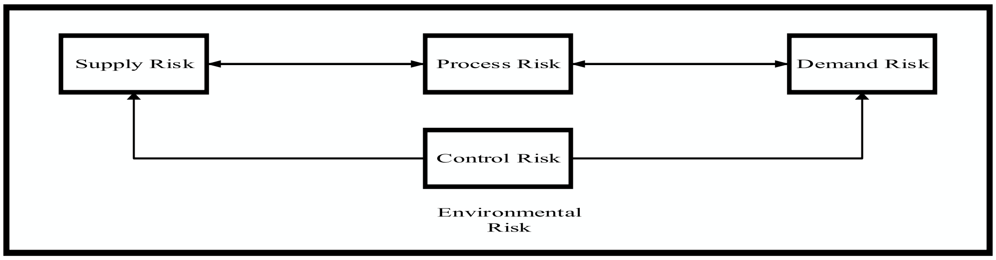

Fig. 1. Sources of risk in a supply chain (Christopher and Peck, 2004).

development and implementation of products, processes, and organizational routines to adapt to changes in customer expectations and market trends (Brown and Eisenhardt, 1997; Wu et al., 2010; Su and Linderman, 2016). Innovative organizations also realize the important role of innovation in solving problems in the future. DHL's investment in city logistics is an example of how innovation can address potential disruptions in transportation and distribution systems (DHL, 2011, 2017). Innovation is also regarded as "a capability of an organization to bring any new, problem-solving idea into use" (Kanter, 1983, p. 20). This perspective on innovation suggests a close relationship between firm innovation capability and response to supply chain disruptions, especially in situations where business contingency plans have not been developed (Golgeci and Ponomarov, 2013). Third, the literature shows a positive relationship between a firm's innovativeness and the firm's response to changes in the market (Mainela and Puhakka, 2008). Innovativeness is regarded as the main driver of the long-term survival of organizations (Christensen et al., 1998), suggesting that innovation can enhance a firm's response to supply chain disruptions and improve its resilience (Christopher and Peck, 2004). Thus, a firm's innovation enhances the firm's organizational competitive position by improving the firm's resilience to disruptions.

Fig. 2 presents the conceptual model that illustrates the relationships between supply chain disruption risks and organizational performance. In this model, we identify four supply chain disruption risks, as shown in Fig. 1. We hypothesize that the effect of supply chain disruptions on organizational performance is moderated by a firm's investment in R&D. We assess organizational performance at both the firm level and the supply chain level (i.e., firm performance and supply chain performance). Because we have four supply chain disruption risk drivers, our two overall hypotheses H_1 and H_2 are each composed of four hypotheses describing the effect of each disruption risk on organizational performance:

H1. : Firm investment in innovation moderates the effect of supply chain disruptions on firm performance. The effect of supply chain disruptions on firm performance is less pronounced for firms with more investment in innovation.

H2. : Firm investment in innovation moderates the effect of supply chain disruptions on supply chain performance. The effect of supply chain disruptions on supply chain performance is less pronounced for firms with more investment in innovation.

5. Methodology

5.1. Sample and data

For data collection, an online survey was developed and administered using the Qualtrics platform. Our population was a registry of 3 million members of the ESOMAR-28 industry panel that covers different industry sectors and organizational characteristics. The survey was submitted to organizations operating in the United States, targeting executives and managers of operations, supply chains, or logistics and transportation. We obtained useful responses from a cross-section of 150 firms, an effective response rate of about 18%. Sample characteristics are shown in Table 1.

5.2. Constructs and measurements

Independent variables. Our unit of analysis for this study is the firm-level response to supply chain disruptions, which was measured in

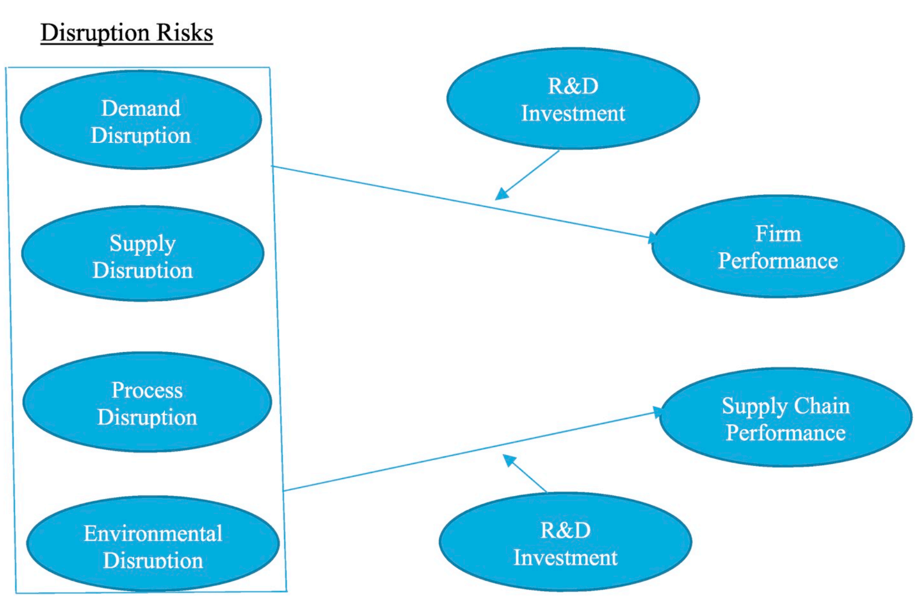

Fig. 2. Theoretical model for innovation and supply chain disruptions.

Table 1
Sample characteristics.

Industry Type	Frequency	Percent
Transportation Services	16	10.6
Information Technology	70	46.6
Manufacturing	43	28.7
Services	21	14.0
Total	150	100.0
Sales **(in USD)**	Frequency	Percent
Up to 1,000,000	13	8.7
1,000,000–10,000,000	35	23.3
10,000,000–100,000,000	31	20.7
100,000,000–500,000,000	42	28.0
500,000,000–1,000,000,000	12	8.0
Over 1,000,000,000	17	11.3
Total	150	100
Number of Employees	Frequency	Percent
Up to 100	31	20.7
101–500	33	22.0
501–1000	35	23.2
1001–2500	16	10.7
2501–5000	19	12.7
Over 5000	16	10.7
Total	150	100.0
Job Categories	Frequency	Percent
Vice President or higher	26	17.3
Manager (General/Project/Plant)	85	56.7
Manager (Supply Chain/Purchasing/Commodity)	22	14.7
Senior Engineer/Engineer	12	8.0
Others	5	3.3
Total	150	100.00

six dimensions. *Supply Disruption* was measured using four items as a result of operations on the upstream of the firm's supply chain, involving activities such as purchasing, supplier relationship, supplier quality, and supply network (Zsidisin et al., 2000; Wagner and Bode, 2008). *Demand Disruption* was measured using four items that evaluate disruption risks related to changes in demand, such as loss of major accounts, volatility of demand, concentration of customer base, short life cycles, and innovative competitors (Xiao and Qi, 2008; Chen and Xiao, 2009). *Process Disruption* was measured using four items that evaluate internal risks of the firm, such as manufacturing yield variability, lengthy set-up times and inflexible processes, equipment unreliability, limited capacity/-bottlenecks, and outsourcing of key business processes (Christopher and Peck, 2004). *Environmental Disruption* was measured using four items that evaluate disruption risks such as natural disasters, terrorism and war, regulatory changes, and strikes (Shishebori and Yousefi-Babadi, 2015). Thus, our structural model examines the impact of four supply chain disruption risk drivers on firm performance and supply chain performance. To measure supply, demand, process, and environmental disruption risks, we used the survey developed by Wagner and Bode (2008).

Dependent variables. Our dependent variables measure performance at the firm level and the supply chain level due to the disruptions. To capture *Firm Performance* due to disruptions, we asked respondents to rate its effects on a 7-point Likert scale (1 = not at all – 7 = to a very large extent). We asked the respondents, "To what extent has your firm in the past 3 years experienced a negative impact in performance as the result of the above sources of risks (1 strongly disagree – 7 strongly agree)". For *Supply Chain Performance*, respondents rated the effects (drop) on four items: order fill capacity, delivery dependability, customer satisfaction, and delivery speed (Wagner and Bode, 2008). For *Firm Performance*, respondents were asked to rate the effects (drop) in the following items: Return on assets, product quality, customer service level, market share, average selling price, and competitive position (Narasimhan et al., 2008). While firm performance and supply chain performance are expected to be correlated (Johnson and Templar, 2011), we decided to examine the impact of supply chain disruptions on both supply chain performance and firm performance to assess the actual impact of disruptions on organizational performance at two levels.

Control variables. The first set of control variables concerns firm characteristics. Larger firms, indicated by a larger number of employees, have more abundant resources and established processes, which might enhance or limit their capability to manage disruptions (Romanelli and Tushman, 1994; Saint-Germain, 2005). Thus, we include firm size as a control variable. The second set of variables includes industry level and disruption frequency (how often disruption is likely to occur). At the industry level, we controlled for any confounding effects of industries by using a vector of four variables. We grouped firms into four clusters based on their industry similarities (transportation, information technology, services, and manufacturing), using manufacturing as the reference category. We also controlled for disruption frequency (by asking how often they face major disruptions), disruption familiarity (by asking how familiar was the disruption), and disruption durability (by asking how long it took to respond to disruptions and resume normal operations).

Moderating variable. We used a firm's investment in R&D (R&D investment) as a measure of the firm's investment in innovation. R&D investment has been used as a proxy for the innovation input of a firm (Baumann and Kritikos, 2016). Research shows that R&D investment is strongly associated with a firm's innovation capability (Hall et al., 2012). We asked each respondent to provide both subjective and objective measures of the firm's investment in R&D. Since we were concerned that some respondents may not be willing to disclose this or may not have actual spending in R&D investment, we included both measures to ensure that we collected data on the firm's R&D investment. Our final data includes 77 responses for objective measures. Since we collected enough data on objective measures of R&D investment, we used this measure for our analysis.

Descriptive statistics. Table 2 shows the means, standard deviations, and zero-order correlations between the constructs used in the study. All constructs have skewedness and kurtosis scores within $\pm$ 2.99, with most scores close to zero, indicating the acceptability of the assumption of normal distribution. To address the non-normality of *R&D Investment*, we followed common practice in the econometrics literature and used the natural logarithm of the values (Fabrizio and Tsolmon, 2014; Xu and Yan, 2014; Welker et al., 2017).

Table 3 shows items for all the constructs used in this study, with factor loadings, average variance extracted (AVE), construct reliabilities, and Cronbach's Alphas. Looking at the correlation measures in Table 2, we realize that *Firm Performance* and *Supply Chain Performance* measures on a 7-point Likert scale are uncorrelated with the objective measure of R&D Investment. While this may be a concern from the convergent validity perspective (Campbell and Fiske, 1959), we realize the distinction in measuring survey-based financial performance and the archival data. Survey-based financial data ask for information to compare financial performance relative to competitors, while the archival data measure the firm's actual performance. In addition, the survey-based performance data are bounded between 1 and 7 on a Likert scale, while objective measures of financial performance are continuous variables that can take on any value.

We also examined whether R&D investment satisfies the requirement of a good moderator in the relationship between supply chain disruptions and performance by testing two conditions: 1) the moderator does not have a strong correlation with the independent variables, and 2) the moderator is theoretically related to the dependent variable. To examine the first requirement, we examine the correlations between R&D investment and supply chain disruption risks (Table 2). While R&D investment is significantly correlated with supply disruptions and process disruptions, the correlations are not very strong: the larger correlation is 0.261. We also realize that R&D investment is related to firm performance (Shin et al., 2017; Lee and Wu, 2016).

Measurement model. Traditional psychometric techniques were used to evaluate construct reliability and validity (Nunnally and

Table 2
Correlations.

	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11
1. Company Size *(Control)*	4687	15325	1.00										
2. Familiarity *(Control)*	5.39	1.38	-.170	1.00									
3. Durability (*Control*)	5.19	1.25	.137	.637**	1.00								
4. Frequency (*Control*)	5.09	1.62	.141	.539**	.599**	1.00							
5. Demand Disruptions	5.52	1.12	-.089	.330**	.376**	.272**	1.00						
6. Supply Disruptions	5.35	1.13	-.046	.596**	.654**	.589**	.697**	1.00					
7. Process Disruptions	5.17	1.37	.023	.570**	.714**	.673**	.514**	.823**	1.00				
8. Environment Disruptions	4.90	1.44	.091	.505**	.664**	.659**	.377**	.676**	.837**	1.00			
9. Firm Performance	5.11	1.31	-.032	.503**	.537**	.599**	.558**	.782**	.730**	.686**	1.00		
10. Supply Chain Performance	5.30	1.32	-.069	.340**	.518**	.363**	.482**	.591**	.635**	.612**	.617**	1.00	
11. R&D Investment ($)	4.23	1.91	.086	.050	.152	.185	.176	.255**	.261**	.044	.096	.059	1.00

*p < .10 **p < .05.

Table 3
Reliabilities.

Scale	Indicator	Loading	Cronbach's α	Composite reliability	AVE
Supply Disruption	SD_1	.79	.81	.87	.47
	SD_2	.72			
	SD_3	.60			
	SD_4	.70			
	SD_5	.58			
Demand Disruption	DD_1	.68	.76	.84	.48
	DD_2	.78			
	DD_3	.55			
	DD_4	.64			
Process Disruption	PD_1	.79	.83	.90	.53
	PD_2	.70			
	PD_3	.65			
	PD_4	.83			
Environment Disruption	ED_1	.90	.90	.93	.65
	ED_2	.83			
	ED_3	.84			
	ED_4	.70			
	ED_5	.73			
	ED_6	.65			
Firm Performance	FP_1	.86	.92	.93	.65
	FP_2	.84			
	FP_3	.82			
	FP_4	.78			
	FP_5	.71			
	FP_6	.83			
Supply Chain Performance	SCP_1	.79	.90	.94	.70
	SCP_2	.86			
	SCP_3	.83			
	SCP_4	.86			

Bernstein, 1994). Reliabilities for all dependent variables were evaluated using Cronbach's alpha: all values range from 0.76 to 0.92.

We examined the validity of the measurement model using AMOS 24.0. Assessment of the model fit using AMOS 24.0 provided an acceptable model fit: $\chi^2/df = 1.9$, RMSEA = (0.073, 0.087) (Hu and Bentler, 1999; Iacobucci, 2010). Factor loadings, Cronbach's alpha, composite reliabilities, and average variance extracted (AVE) estimates were examined to ensure convergent validity of constructs. Convergent validity and internal consistency were also supported in an examination of the composite reliabilities. All composite reliability values were greater than the recommended threshold of 0.7 reported in the literature (Hair et al., 2010).

Common method bias and non-response testing. To control for common method bias, we determined the number of factors that are necessary to account for the variance in the variables using Harman's one-factor test. If a substantial amount of common method variance is present, one of the following two situations occurs: 1) a single factor will emerge from the factor analysis, or 2) one general factor will account for the majority of the covariance among the variables (Podsakoff et al., 2003). The unrotated principal component factor analysis revealed the presence of eight distinct factors with eigenvalues greater than 1.0, rather than a single factor. Four factors together accounted for 68% of the total variance; the first (largest) factor did not account for most of the variance (40%). Thus, our empirical findings suggest that common method variance is not of great concern and is unlikely to confound the interpretation of the results.

6. Results

Hypothesis testing. Table 4 shows the results from our model. Since our objective was to investigate the moderating effect of firm innovation on the relationship between supply chain disruption risks and organizational performance, we used a set of control variables that appear to be correlated with the dependent variables. These control variables are disruption frequency, disruption durability, and disruption familiarity. We also controlled for firm size (measured by the number of employees), and industry (represented by a dummy vector of four variables, treating manufacturing as the reference group). The results are presented separately for each organizational outcome: *Firm Performance* (Table 4), and *Supply Chain Performance* (Table 5).

Model 1 examines the moderating effect of *R&D Investment* on the relationship between *Demand Disruption* and *Firm Performance*. Regarding the impact of control variables on our performance outcome, we find a significant effect of *Disruption Frequency* on *Firm Performance* (ß = .433, p < .05). Specifically, our first hypothesis stated that the

Table 4
Regression coefficients and prediction estimates (firm performance).

	Model 1	Model 2	Model 3	Model 4
Control Variables				
Firm size	-.055	-.043	-.092	-.122
Disruption frequency	.433**	.278**	.226*	.209*
Disruption durability	.103	-.029	-.068	-.001
Disruption familiarity	.093	.015	.095	.097
Industry group 1	-.004	-.027	-.047	-.096
Industry group 2	.061	.047	.075	.059
Industry group 3	.124	.064	-.021	-.065
Demand Disruption	.838			
Supply Disruption		1.204**		
Process Disruption			1.371**	
Environmental Disruption				.832**
R&D Investment	.609	.691	.814*	.309
Demand Disruption × R&D Investment	-.859*			
Supply Disruption × R&D Investment		-.973*		
Process Disruption × R&D Investment			−1.204**	
Environmental Disruption × R&D Investment				-.336
Measures of Fit				
R^2_{adj}	0.52	0.61	0.55	.50

**p < .05, *p < .10.

Table 5
Regression coefficients and prediction estimates (supply chain performance).

	Model 1	Model 2	Model 3	Model 4
Control Variables				
Firm size	-.110	-.111	-.154*	-.178*
Disruption frequency	.151	.055	-.006	-.085
Disruption durability	.359**	.295**	.186	.243*
Disruption familiarity	.090	-.135	-.074	-.057
Transportation	-.285*	-.263*	-.162	-.132
Information Technology	-.339*	-.338*	-.249	-.198
Service	-.364**	-.339*	-.211	-.147
Demand Disruption	.259			
Supply Disruption		.910**		
Process Disruption			1.735**	
Environmental Disruption				1.109**
R&D Investment	-.258	.479	1.186**	.537
Demand Disruption × R&D Investment	.191			
Supply Disruption × R&D Investment		-.783		
Process Disruption × R&D Investment			−1.851**	
Environmental Disruption × R&D Investment				-.791*
Measures of Fit				
R^2_{adj}	0.37	0.39	0.47	.38

**p < .05, *p < .10.

impact of *Demand Disruption* on *Firm Performance* would be less pronounced for firms with higher levels of *R&D Investment*. Consistent with our expectations, the interaction term (*Demand Disruption* × *R&D Investment*) is statistically significant and negative ($\beta_{\text{Demand Disruption} \times \text{R\&D Investment}} = -0.859$, $p < .10$). The negative sign for this coefficient indicates that the relationship between demand disruption and firm performance is less pronounced for firms with higher levels of R&D investment (Aiken and West, 1991). Fig. 3 presents a plot of this relationship. Consistent with our theorizing, we see that the slope of the relationship between *Demand Disruption* and *Firm Performance* is smaller for firms with higher levels of R&D investment.

Model 2 tests the theorized interaction between *Supply Disruption* and *Firm Performance*. H_{1b} proposes that the impact of *Supply Disruption* on *Firm Performance* is less pronounced for firms with higher levels of *R&D Investment*. Consistent with our expectations, the two-way interaction between *Supply Disruption* and *Firm Performance* is statistically significant and negative ($\beta_{\text{Supply Disruption} \times \text{R\&D Investment}} = -0.973$, $p < .10$), indicating that the impact of *Supply Disruption* on *Firm Performance* is less pronounced for firms with higher levels of *R&D Investment*. Fig. 4 presents the graphical representation of the moderating role of *R&D Investment* on the relationship between *Supply Disruption* and *Firm Performance*.

Model 3 tests the interaction effect of *Process Disruption* and *R&D Investment*. Consistent with our expectations, the interaction term (Process Disruption × R&D Investment) is negative ($\beta_{\text{Process Disruption} \times \text{R\&D Investment}} = -1.204$, $p < .05$). The negative sign for this coefficient indicates that the effect of *Process Disruption* on *Firm Performance* is less pronounced for firms with higher levels of *R&D Investment* (Aiken and West, 1991). Fig. 5 shows this interaction effect.

Model 4 tests the theorized two-way interaction between *Environmental Disruption* and *R&D Investment*. H_{1d} proposes that the effect of *Environmental Disruption* on *Firm Performance* is more pronounced for firms with a lower level of *R&D Investment*. Consistent with our theorizing, the two-way interaction term (Environmental Disruption × R&D Investment) is negative ($\beta_{\text{Environmental Disruption} \times \text{R\&D Investment}} = -0.336$, $p > .10$), indicating that the two-way interaction effect of *Environmental Disruption* and *Firm Performance* is less pronounced for firms with higher levels of *R&D Investment*. Fig. 6 presents the graphical representation of the moderating role of *R&D Investment* on the relationship between *Environmental Disruption* and *Firm Performance*.

Our second set of hypotheses pertains to the relationship between R&D investment, supply chain disruption risks, and supply chain performance (Table 5).

Models 1 through 4 present the moderating effect of *R&D Investment* on the relationship between *Process Disruption* and *Supply Chain Performance*. In Models 1 and 2, the coefficients of the interaction terms are not statistically significant ($\beta_{\text{Demand Disruption} \times \text{R\&D Investment}} = 0.191$ $p > .10$: $\beta_{\text{Supply Disruption} \times \text{R\&D Investment}} = -0.783$, $p > .10$). In Model 3, the interaction term between *Process Disruption* and *R&D Investment* is statistically significant and negative in the anticipated direction ($\beta_{\text{Process Disruption} \times \text{R\&D Investment}} = -1.851$, $p < .05$). Fig. 7 depicts this interaction effect.

Model 4 examines our hypothesis pertaining to the moderating impact of *R&D Investment* on the relationship between *Environmental Disruption* and *Supply Chain Performance*. Consistent with our hypothesis, the interaction term is negative and statistically significant ($\beta_{\text{Environmental Disruption} \times \text{R\&D Investment}} = -.791$, $p < .10$), providing support for the validity of our hypothesis. Fig. 8 provides a plot of this interaction.

7. Robustness test

Bootstrapping. One concern related to empirical data is that in some situations, the true population distribution of the sample does not meet the assumptions of the closest approximate distribution. This may be the case with financial measures, where the true population mean is heavily skewed. In these situations, using the procedure for the standard error of the mean for the normal distribution would not be appropriate due to the skewness (DiCiccio and Efron, 1996). To address this concern, we use the bootstrapping method to empirically derive the standard error of the mean. We performed the bias-corrected bootstrapping method in a structural equation model using AMOS 24.0 at 90 percent confidence interval to develop point estimates and confidence intervals for

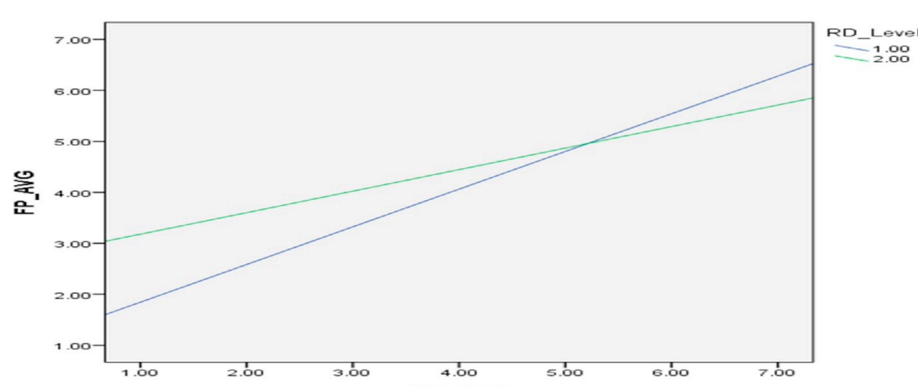

Fig. 3. The interaction effect of R&D investment – demand disruption.

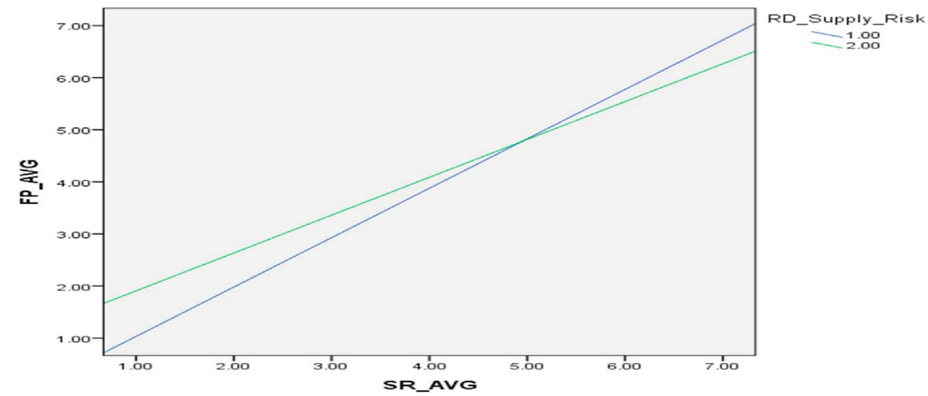

Fig. 4. The interaction effect of R&D investment – supply disruption.

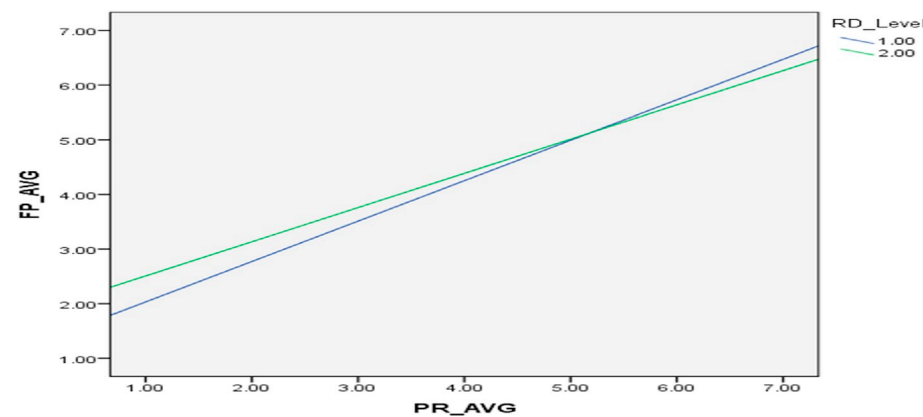

Fig. 5. The interaction effect of R&D investment – process disruption.

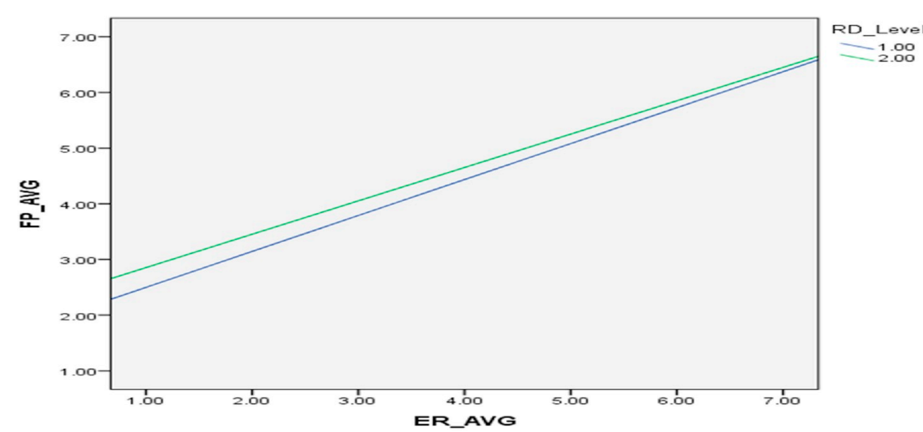

Fig. 6. The interaction effect of R&D investment – environmental disruption.

regression coefficients for the interaction effects (Efron and Tibshirani, 1994; Davison and Hinkley, 1997). The results are provided in Table 6.

The results are provided for both firm performance and supply chain performance. Since bootstrapping uses a different statistical procedure to assess the standard error of the mean, we expect that the point estimate for the regression coefficient obtained from the bootstrapping method would be different. For firm performance, supply disruption and process disruption have the most pronounced impact on firm performance, which is consistent with the results presented in Table 4. For supply chain performance, and process disruption, supply disruption and environmental disruption have the most pronounced impact on supply chain performance. This is consistent with the results presented in Table 5.

8. Discussion

Our study provides several important contributions to the theory and practice of supply chain risk management and disruption mitigation strategies. We outline these findings in the following sections on theoretical contributions and managerial implications.

8.1. Theoretical contributions

Our first contribution in this study pertains to providing empirical

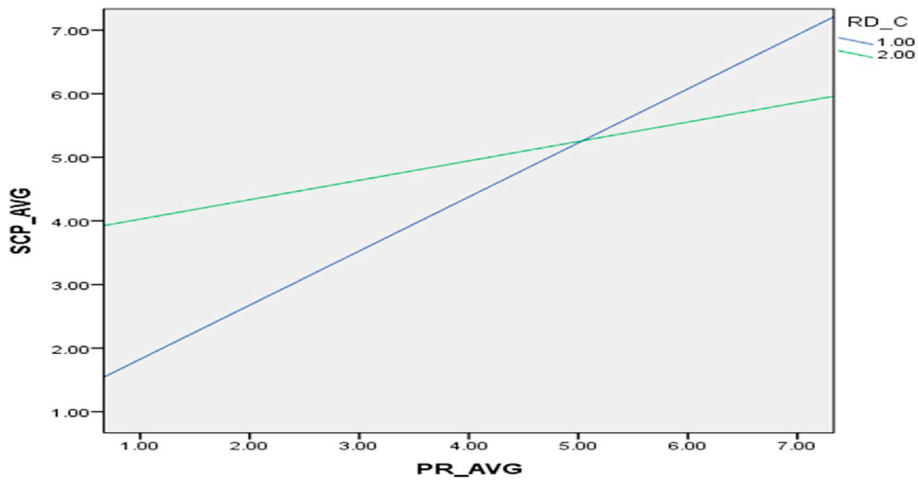

Fig. 7. The interaction effect of R&D investment – process disruption.

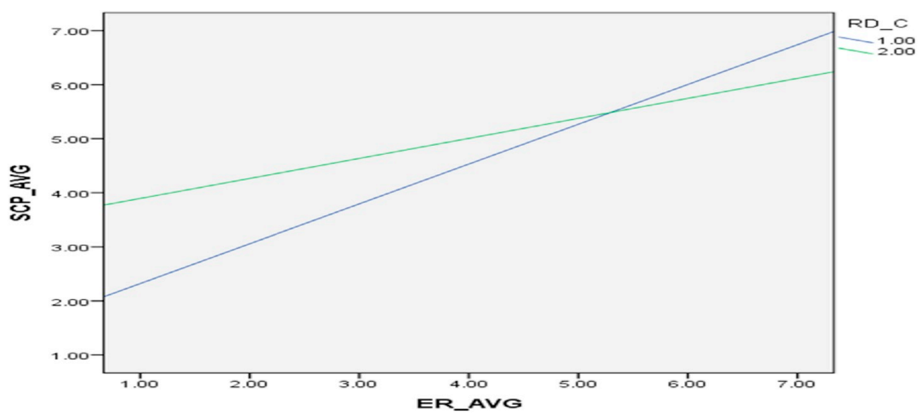

Fig. 8. The interaction effect of R&D investment – environmental disruption.

Table 6
Bias-corrected bootstrapping results for the interaction effects.

Outcome	Path	Estimate	Lower	Upper
Firm Performance (FP)	Supply Disruption × R&D Investment	-.611	−1.014	.472
	Demand Disruption × R&D Investment	-.568	-.959	.876
	Process Disruption × R&D Investment	-.770	−1.005	-.278
	Environment Disruption × R&D Investment	-.153	-.657	.970
Supply Chain Performance (SCP)	Supply Disruption × R&D Investment	-.453	-.985	1.226
	Demand Disruption × R&D Investment	-.207	-.805	1.272
	Process Disruption × R&D Investment	-.851	-.993	-.567
	Environment Disruption × R&D Investment	-.449	-.799	.678

evidence on the importance of a firm's investment in research and development (R&D) as a disruption mitigation strategy. Traditionally, investment in R&D has been regarded as a means to improve a firm's response to changes in the market (which can be related to demand disruption in terms of responding to volatile customer demand and changing customer preferences). We were able to show that investment in R&D has a much broader effect and contributes to improving organizational resilience to supply chain disruptions. While the importance of firm innovation in improving resilience has been discussed in prior studies (e.g., Golgeci and Ponomarov, 2013; Herrgard et al., 2017; Parast et al., 2019; Sabahi and Parast, 2019), the majority of our understanding of the relationship between firm innovation and firm resilience was mainly limited to anecdotal evidence and case studies. To the best of our knowledge, this is the first empirical study that demonstrates the impact of R&D investment as a disruption mitigation capability or resilience enhancer with respect to varied supply chain disruption risk drivers. Thus, our findings support earlier results: the empirical results of Golgeci and Ponomarov (2013) that a firm's innovativeness and innovation magnitude are positively associated with supply chain resilience; and the findings of the models proposed by Kamalahmadi and Parast (2016) and Sabahi and Parast (2019) that firm innovation enhances firm resilience to supply chain disruptions.

Our second contribution pertains to the relative importance of the effect of a firm's investment in R&D on mitigating the negative impact of supply chain disruptions on firm performance and supply chain performance. We find that the magnitude of the impact is different for firm performance and supply chain performance. R&D investment has the most pronounced impact on mitigating the negative effects on firm performance of process disruption (ß = −1.204), supply disruption (ß = −0.973), and demand disruption (ß = −0.859). R&D investment has the most pronounced impact on mitigating the negative effects on supply chain performance of process disruption (ß = -1.85) and environmental disruption (ß = -0.791).

The third contribution of our study is to provide empirical evidence on the relative importance of the types of disruption in terms of

Frequency, *Durability*, and *Familiarity*, and their impact on supply chain performance and firm performance. Looking at Table 4, we notice that *Disruption Frequency* is significantly related to *Firm Performance* in all four models (Models 1 through 4). Turning to Table 5, we see that *Disruption Durability* is significantly related to *Supply Chain Performance* in the anticipated direction. These are important findings because they provide empirical evidence on two issues: how organizational performance outcomes are affected by the frequency and durability of disruptions, and how organizations should make decisions regarding the design of their supply chains to minimize the negative impact of disruptions. As an example, the importance of regionalization in supply chain design can be related to the frequency of disruptions (Chopra and Sodhi, 2014; Kamalahmadi and Parast, 2016). If firms are extending their supply chains to different regions, one important factor that should be considered in the selection of regions should be the frequency of disruption, to improve firm performance due to disruptions. We should keep in mind that a firm's performance is also related to how well the firm's supply chain performs (Johnson and Templar, 2011). Thus, in the design of a supply chain, firms need to take into account the durability of disruptions in their decisions.

Another finding of this study is the evidence of the moderating effect of a firm's R&D investment in mitigating the negative effect of environmental disruptions only on supply chain performance, not on firm performance. These "low probability, high impact" incidents do not occur frequently; thus, firms, on average, are not expected to be significantly impacted by environmental disruptions. Because environmental disruptions are not considered as contextual variables, firms may not be able to effectively incorporate them into their supply chain decisions (Pettigrew and Whipp, 1993; Wagner and Bode, 2008). Nevertheless, firm investment in R&D provides a platform to improve communication and collaboration across the firm (Saren, 1987; Robertson and Gatignon, 1987). Such investments in R&D provide spillover effects that improve organizational infrastructure in several areas that can support firm response and resilience to disruptions.

Our study complements prior research that examined the effect of R&D investment on firm performance. Empirical studies show that R&D investment improves a firm's performance (Ehie and Olibe, 2010). However, the role of R&D investment in enhancing organizational capabilities to mitigate supply chain disruptions was not fully examined. In that respect, our study completes previous work on the relationship between R&D investment and firm performance, in that investment in R&D can be viewed as a means to improve a firm's performance through the development of new products and services, and investment in R&D also creates capabilities in a firm that enhance the firm's response to environmental changes such as economic recession (Jung et al., 2018). Thus, R&D investment can be regarded as a dynamic capability that improves an organization's capability to respond to both "positive" and "negative" changes. The positive changes are realized in the view that R&D investment increases a firm's innovation capability and organizational performance (Alam et al., 2020; Patel et al., 2018), which was widely recognized. What was less obvious is the ability of investment in R&D to improve a firm's response to negative changes — changes that are imposed on the firm by the business environment as a result of supply chain disruptions.

It is important to note that our results showed differences in the effect of R&D investment on the relationship between supply chain disruption risk drivers on firm performance vs. supply chain performance. Our results show that R&D investment mitigates the effects of process disruptions, supply disruptions, and demand disruptions on firm performance. In contrast, R&D investment mitigates the effects of process disruptions and environmental disruptions on supply chain performance. One possible explanation for this difference in the impact of R&D investment is the difference between the metrics used for firm performance and the metrics used for supply chain performance. Firm performance is evaluated using a combination of financial and non-financial measures such as return on assets, product quality, market share, level of customer service, average selling price, and overall competitive position; the overall emphasis is on financial performance. In contrast, supply chain performance is assessed using non-financial outcomes such as capacity to fill orders, customer satisfaction in the supply chain, delivery, and speed. Therefore, we expect to see differences between the effect of R&D investment on firm performance and supply chain performance with respect to different sources of disruptions. Because the purpose of R&D activities is to improve long-term firm performance through improving organizational capabilities in the design and development of new products and services that create a competitive edge for the firm, R&D investment has a much stronger impact on mitigating the negative effect of supply chain disruptions on firm performance compared to supply chain performance. This emphasis on financial vs. non-financial measures is also reflected in the moderating effect of R&D investment on the relationship between mitigating environmental risk and supply chain performance. Regardless of the type of disruptions that originate from the business environment, such events negatively impact a firm's financial performance (Hendricks and Singhal, 2005). However, R&D investment has a strong relationship with organizational capabilities such as adaptability, flexibility, and agility, which impact organizational processes that create products and services (Ettlie, 1998; Tuominen et al., 2004; Santiago and Bifano, 2005; Wang and Yang, 2012).

The positive impact of R&D investment on mitigating the effect of process disruption on both firm performance and supply chain performance can be attributed to the importance of organizational processes, which are the building blocks of supply chain processes (Trkman et al., 2007; Pradabwong et al., 2017; Boon-Itt et al., 2017). The literature identifies supply chain processes as a source of competitive advantage and value creation (Parast and Spillan, 2014; Ren et al., 2015). R&D investment has a much broader effect than creating new products and services that meet customer demand; it enhances organizational and inter-organizational processes that make organizations and their supply chains more adaptive to changes in the business environment. R&D investment enhances the absorptive capacity of an organization (Cohen and Levinthal, 1990; Griffith et al., 2004) and improves firm performance (Artz et al., 2010). At the firm level, R&D investment increases product and market innovation and enhances a firm's adaptability to market changes (Wang and Ahmed, 2007). R&D investment improves organizational response to changes on both the supply side and market side while it improves organizational processes. Our results align with the existing literature that discusses the positive role of R&D in maintaining organizational performance in dynamic and turbulent environments (Sher and Yang, 2005; Lome et al., 2016; Alam et al., 2020). Our results show that the effect of R&D investment on mitigating the effect of environmental disruptions is more pronounced in improving supply chain performance measures (such as order fill capacity, customer satisfaction in the supply chain, delivery, and speed) that are more embedded in organizational and inter-organizational processes compared to firm performance measures that are primarily concerned with financial outcomes and the competitive position of the firm. Thus, the impact of R&D investment on mitigating supply chain disruptions can be attributed to how investment in innovation enhances process innovation across the supply chain (Un and Asakawa, 2015).

8.2. Managerial implications

The results of our study provide several insights for top-level managers who are concerned with improving their organizational resilience to supply chain disruptions. Our first managerial implication pertains to promoting investment in innovation across the organization. Investment in research and development increases organizational resilience to disruptions. Second, managers should be aware that the impact of R&D investment in mitigating the negative effects of disruptions is not the same for all sources of disruption risks. Managers need to identify the major sources of disruption risks in their supply chain and develop their

R&D investment plans. Third, managers investing in disruption mitigation strategies should be aware of the potential trade-off between strategies at the supply chain level vs. the firm level. Because supply chain disruptions have different impacts on firm performance and supply chain performance outcomes, supply chain managers would be facing a challenging decision on how to address firm performance vs. supply chain performance from a perspective of risk management. This supports the importance of supply chain collaboration as a risk mitigation strategy, which requires a firm and its supply chain members to work collaboratively to mitigate disruptions across the supply chain (Chen et al., 2013).

9. Limitations and future research

Our study is subject to several limitations. First, the data used in the study is cross-sectional, which has its own limitations in terms of capturing an individual's perception related to performance outcomes. In addition, there are some limitations in assessing causality using cross-sectional data. While we were able to mitigate the effects of these limitations through capturing objective measures of R&D and firm performance, future studies should develop additional objective measures of supply chain risks as well as consider additional objective measures of firm performance. We realize that obtaining objective measures for variables such as supply chain disruption risks would be a challenge; however, from a perspective of research design, conducting research using longitudinal data can provide more insight to ensure causality. In addition, future studies can examine the mediating effect of organizational practices on the relationship between supply chain disruptions and supply chain performance. For example, the impact of supply chain disruptions on firm performance and the impact on supply chain performance could be mediated through process risk (Chen et al., 2013). More insight into how supply chain disruptions impact firm performance could come from development of a more nuanced model that examines the mediating effect of organizational and supply-chain-level practices and capabilities on the relationship of supply chain disruptions to firm performance and supply chain performance. Future research can also look more deeply into different types of innovation and their impact on improving resilience. Because different types of innovation (e.g., product innovation, process innovation, and management innovation) develop specific capabilities at the firm, it would be interesting to examine how the type of innovation can impact a firm's resilience to supply chain disruptions.

In this study, we used R&D investment as a measure to assess the innovation capability of a firm. R&D investment can provide useful insights into the strategic orientation of a firm toward innovation and how the firm sees investment in innovation from a business viewpoint (Hall et al., 2012). However, R&D investment may not fully capture a firm's innovation capability. For that reason, scholars suggest using *R&D Intensity* as a measure that captures the relative importance of innovation for a firm. *R&D Intensity* is determined by dividing R&D investment by total sales, or as R&D investment per full-time-equivalent employee (Baumann and Kritikos, 2016). We also know that R&D investment increases with scale (Baldwin and Scott, 1987; Scherer and Ross, 1990; Cohen, 2010). Therefore, one can expect that on average, R&D investment and R&D intensity should be highly correlated. A more practical approach to capture a firm's innovation capability is to use *R&D Efficiency*, which is determined by dividing *R&D Investment* by the number of patents. *R&D Efficiency* provides a better assessment of a firm's innovation capability because it measures how efficiently a firm can translate input (investment in R&D) to valuable products and services.

Since a firm's research activities are distinct from its development and commercialization efforts (Karlsson et al., 2004), future studies should make a distinction between different types of R&D investments to obtain a more nuanced understanding of how investment in different forms of R&D can improve a firm's capacity for innovation and its response to supply chain disruptions. It would be interesting to examine how investments in different types of R&D (basic, applied, and development) affect a firm's response to mitigate the negative effects of supply chain disruptions.

Another possible limitation of this study is the use of a single respondent from each firm. While we were able to collect different measures of firm performance and supply chain performance, future studies of supply chain risk management should obtain additional data sources for measuring firm performance and supply chain performance. Finally, as described above, the data for this survey were collected from U.S. firms, which operate in a specific social, economic, and legal business environment. Therefore, the results can be generalized for firms based in countries with a similar political, economic, and geographic setting. Future studies should investigate the validity of our results in other regions with a different business environment.

CRediT authorship contribution statement

Mahour Mellat Parast: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Investigation, Project administration, Resources, Supervision, Visualization, Writing - original draft, Writing - review & editing.

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Appendix A

Supply chain risk management survey

I. Sources of risk

To what extent has your firm in the past 3 years experienced a negative impact in supply chain management due to the following sources of risk (1 strongly disagree – 7 strongly agree).

Demand risk.

	Strongly Neither Agree Strongly Not Disagree Nor Disagree Agree Applicable
Unanticipated or very volatile demand.	1 - 2–3 - 4–5 - 6–7 X
Insufficient or distorted information from your customer about orders or demand quantities.	1 - 2–3 - 4–5 - 6–7 X
Unusual customer payment delays.	1 - 2–3 - 4–5 - 6–7 X
Request from the customer to expedite pending order (s).	1 - 2–3 - 4–5 - 6–7 X

Supply risk.

	Strongly Neither Agree Strongly Not Disagree Nor Disagree Agree Applicable
Poor logistics performance of suppliers (e.g., delivery dependability, order fill capacity).	1 - 2–3 - 4–5 - 6–7 X
Supplier quality problems.	1 - 2–3 - 4–5 - 6–7 X
Sudden demise of a supplier (e.g., due to bankruptcy).	1 - 2–3 - 4–5 - 6–7 X
Poor logistics performance of logistics service providers.	1 - 2–3 - 4–5 - 6–7 X
Capacity fluctuations or shortages on the supply markets.	1 - 2–3 - 4–5 - 6–7 X

Process risk.

	Strongly Neither Agree Strongly Not Disagree Nor Disagree Agree Applicable
Downtime or loss of own production capacity due to local disruptions (e.g., labor strike, fire, explosion, industrial accidents).	1 - 2–3 - 4–5 - 6–7 X
Perturbation or breakdown of internal IT infrastructure (e.g., caused by computer viruses, software bugs).	1 - 2–3 - 4–5 - 6–7 X
Loss of own production capacity due to technical reasons (e.g., machine deterioration).	1 - 2–3 - 4–5 - 6–7 X
Perturbation or breakdown of external IT infrastructure.	1 - 2–3 - 4–5 - 6–7 X

Environment Risk.

	Strongly Neither Agree Strongly Not Disagree Nor Disagree Agree Applicable
Political instability, war, civil unrest, or other socio-political crises.	1 - 2–3 - 4–5 - 6–7 X
International terror attacks (e.g. 2005 London, 2004 Madrid).	1 - 2–3 - 4–5 - 6–7 X
Disease or epidemics (e.g. SARS, foot and mouth disease, Ebola).	1 - 2–3 - 4–5 - 6–7 X
Natural disasters (e.g., earthquake, flooding, extreme climate, tsunami)	1 - 2–3 - 4–5 - 6–7 X
Changes in the political environment due to the introduction of new laws, stipulations, etc.	1 - 2–3 - 4–5 - 6–7 X
Administrative barriers for the setup or operation of supply chains (e.g., authorizations).	1 - 2–3 - 4–5 - 6–7 X

II. Performance outcomes

To what extent has your firm in the past 3 years experienced a negative impact in performance as the result of the above sources of risks (1 strongly disagree – 7 strongly agree).

Supply Chain Performance.

	Strongly Neither Agree Strongly Not Disagree Nor Disagree Agree Applicable
Drop in order fill capacity: Provision of desired quantities on a consistent basis.	1 - 2–3 - 4–5 - 6–7 X
Drop in delivery dependability: Meeting quoted or anticipated delivery dates and quantities on a consistent basis.	1 - 2–3 - 4–5 - 6–7 X
Drop in customer satisfaction: Meeting customer satisfaction with supply chain performance on a consistent basis.	1 - 2–3 - 4–5 - 6–7 X
Drop in delivery speed: Time between order receipt and customer delivery.	1 - 2–3 - 4–5 - 6–7 X

Firm performance.

	Strongly Neither Agree Strongly Not Disagree Nor Disagree Agree Applicable
Drop in return on assets.	1 - 2–3 - 4–5 - 6–7 X
Drop in overall product quality.	1 - 2–3 - 4–5 - 6–7 X
Drop in overall customer service levels.	1 - 2–3 - 4–5 - 6–7 X
Drop in market share.	1 - 2–3 - 4–5 - 6–7 X
Drop in average selling price (high performance means higher average price).	1 - 2–3 - 4–5 - 6–7 X
Drop in overall competitive position.	1 - 2–3 - 4–5 - 6–7 X

III. Miscellaneous questions

Please answer the following questions about yourself and your company:

1. How many years have you worked in your current job? _ 0–2 yrs, _ 3–5 yrs, _ 6–10 years, _ 10+ years

2. Number of years your company has been in business: _____
3. Which of the following most accurately describes your position or title in your organization?
   [ ] Vice President or higher [ ] Purchasing Manager
   [ ] Project Manager [ ] Plant Manager
   [ ] Senior Engineer [ ] General Manager
   [ ] Engineer [ ] Commodity Manager or Senior Buyer
   [ ] Supply Chain Manager [ ] Other (please specify) _________
4. Please select your firm's business environment:
   [ ] Transportation/Logistics [ ] Information Technology
   [ ] Finance/Insurance [ ] Consulting
   [ ] Healthcare [ ] Manufacturing
   [ ] Service industries [ ] Not-for-Profit
   [ ] Utility [ ] Wholesale/Distributor
   [ ] Telecommunication [ ] Government/Military
   [ ] Merchandiser/Retailer [ ] Other (please specify):__________
5. Please provide your company's average investment in research and development R&D in the last three years ___ $

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijpe.2020.107671.

References

Aiken, L.S., West, S.G., 1991. Multiple Regression: Testing and Interpreting Interactions. Sage Publications, Thousand Oaks, CA.

Akgün, A.E., Keskin, H., 2014. Organisational resilience capacity and firm product innovativeness and performance. Int. J. Prod. Res. 52, 6918–6937.

Alam, A., Uddin, M., Yazdifar, H., Shafique, S., Lartey, T., 2020. R&D investment, firm performance and moderating role of system and safeguard: evidence from emerging markets. J. Bus. Res. 106, 94–105.

Allenby, B., Fink, J., 2005. Toward inherently secure and resilient societies. Science 309, 1034–1036.

Ambulkar, S., Blackhurst, J., Grawe, S., 2015. Firm's resilience to supply chain disruptions: scale development and empirical examination. J. Oper. Manag. 33–34, 111–122.

Andergassen, R., Nardini, F., Ricottilli, M., 2015. Emergence and resilience in a model of innovation and network formation. Network. Spatial Econ. 15, 293–311.

Artz, K., Norman, P., Hatfield, D., Cardinal, L., 2010. A longitudinal study of the impact of R&D, patents, and product innovation on firm performance. J. Prod. Innovat. Manag. 27 (5), 725–740.

Azadegan, A., Dooley, K.J., 2010. Supplier innovativeness, organizational learning styles and manufacturer performance: an empirical assessment. J. Oper. Manag. 28, 488–505.

Azadegan, A., Parast, M.M., Lucianetti, L., Nishant, R., Blackhurst, J., 2019. Supply chain disruptions and business continuity: an empirical assessment. Decision Sciences Journal (in press).

Baldwin, W.L., Scott, J.T., 1987. Market Structure and Technological Change. Harwood Academic Publishers, New York, NY.

Barreto, I., 2010. Dynamic capabilities: a review of past research and an agenda for the future. J. Manag. 36, 256–280.

Baumann, J., Kritikos, A.S., 2016. The link between R&D, innovation and productivity: are micro firms different? Res. Pol. 45 (6), 1263–1274.

Blackhurst, J., Craighead, C.W., Elkins, D., Handfield, R.B., 2005. An empirically derived agenda of critical research issues for managing supply-chain disruptions. Int. J. Prod. Res. 43, 4067–4081.

Blackhurst, J., Dunn, J., Craighead, C., 2011. An empirically derived framework of global supply resiliency. J. Bus. Logist. 32, 374–391.

Blome, C., Schoenherr, T., Rexhausen, D., 2013. Antecedents and enablers of supply chain agility and its effect on performance: a dynamic capabilities perspective. Int. J. Prod. Res. 51, 1295–1318.

Bloomberg, J., 2014. Innovation: the Flip Side of Resilience. Forbes September 3.

Bode, C., Wagner, S.M., Petersen, K., Ellram, L.M., 2011. Disruptions: insights from information processing and resource dependency perspectives. Acad. Manag. J. 54, 833–856.

Boon-Itt, S., Wong, C.Y., Wong, C.W.Y., 2017. Service supply chain management process capabilities: measurement development. Int. J. Prod. Econ. 193, 1–11.

Brede, M., de Vries, B.J.M., 2009. Networks that optimize a trade-off between efficiency and dynamical resilience. In: Zhou, J. (Ed.), Complex Sciences. Complex 2009, Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol. 5. Springer, Berlin, Heidelberg.

Brown, S.L., Eisenhardt, K.M., 1997. The art of continuous change: linking complexity theory and time-paced evolution in relentlessly shifting organizations. Adm. Sci. Q. 42, 1–34.

Campbell, D.T., Fiske, D.W., 1959. Convergent and discriminant validation by the multitrait-multimethod matrix. Psychol. Bull. 56 (2), 81–105.

Carvalho, H., Barroso, A.P., Machado, V.H., Azevedo, S., Cruz-Machado, V., 2012. Supply chain redesign for resilience using simulation. Comput. Ind. Eng. 62, 329–341.

Chen, X., Xiao, T., 2009. Demand disruption and coordination of the supply chain with a dominant retailer. Eur. J. Oper. Res. 197 (1), 225–234.

Chen, J., Amrik, S., Sohal, A.S., Prajogo, D.I., 2013. Supply chain operational risk mitigation: a collaborative approach. Int. J. Prod. Res. 51 (7), 2186–2199.

Cho, H.J., Pucik, V., 2005. Relationship between innovativeness, quality, growth, profitability, and market value. Strat. Manag. J. 26, 555–575.

Chopra, S., Sodhi, M.S., 2014. Reducing the risk of supply chain disruption. MIT Sloan Manag. Rev. 55, 72–80.

Christensen, C., Suarez, F., Utterback, J., 1998. Strategies for survival in fast-changing industries. Manag. Sci. 4, 207–220.

Christopher, M., 2005. Logistics and Supply Chain Management: Creating Value-Added Networks. Pearson Education, Harlow.

Christopher, M., Peck, H., 2004. Building the resilient supply chain. Int. J. Logist. Manag. 5, 1–13.

Cohen, W., 2010. Fifty years of empirical studies of innovative activity and performance. In: Hall, B.H., Rosenberg, N. (Eds.), Handbook of the Economics of Innovation. North Holland Elsevier, Amsterdam, The Netherlands.

Cohen, W.M., Levinthal, D.A., 1990. Absorptive capacity: a new perspective on learning and innovation. Adm. Sci. Q. 35 (1), 128–152.

Cohen, M.A., Cull, C., Lee, H.L., Willen, D., 2000. Saturn's supply-chain innovation: high value in after-sales service. Sloan Manag. Rev. 41 (4), 93–101.

Craighead, C.W., Blackhurst, J., Rungtusanatham, M.J., Handfield, R.B., 2007. The severity of supply chain disruptions: design characteristics and mitigation capabilities. Decis. Sci. J. 38, 131–156.

Crossan, M.M., Apaydin, M., 2010. A multi-dimensional framework of organizational innovation: a systematic review of the literature. J. Manag. Stud. 47, 1154–1191.

Davison, A.C., Hinkley, D.V., 1997. Bootstrap Methods and Their Application. Cambridge University Press, Cambridge, UK.

de Oliveira Teixeira, E., Werther Jr., W.B., 2013. Resilience: continuous renewal ofcompetitive advantages. Bus. Horiz. 56, 333–342.

Defee, C.C., Fugate, B.S., 2010. Changing perspective of capabilities in the dynamic supply chain era. Int. J. Logist. Manag. 21, 180–206.

Delmas, M.A., 2002. Innovating against European rigidities: institutional environment and dynamic capabilities. J. High Technol. Manag. Res. 13, 19–43.

DHL, 2011. DHL launches first open innovation competition on city logistics. http://www.dpdhl.com/en/media_relations/press_release/2011/dhl_launches_open_innovation_competition_city_logistics.htmw. (Accessed 2 November 2017).

DHL, 2017. DHL launches new logistics innovation contest. http://www.mmh.com/article/dhl_launches_new_logistics_innvation_contest. (Accessed 2 November 2017).

Di Stefano, G., Peteraf, M., Verona, G., 2010. Dynamic capabilities deconstructed: a bibliographic investigation into the origins, development, and future directions of the research domain. Ind. Corp. Change 19, 1187–1204.

DiCiccio, T.J., Efron, B., 1996. Bootstrap confidence intervals. Stat. Sci. 11, 189–228.

Dierickx, I., Cool, K., 1989. Asset stock accumulation and sustainability of competitive advantage. Manag. Sci. 35, 1504–1511.

Efron, B., Tibshirani, R.J., 1994. An Introduction to the Bootstrap. Chapman and Hall, London, UK.

Ehie, I.C., Olibe, K., 2010. The effect of R&D investment on firm value: an examination of US manufacturing and service industries. Int. J. Prod. Econ. 128, 127–135.

Ellonen, H.K., Wikström, P., Jantunen, A., 2009. Linking dynamic-capability portfolios and innovation outcomes. Technovation 29, 753–762.

Ettlie, J.E., 1998. R&D and global manufacturing performance. Manag. Sci. 44 (1), 1–11.

Fabrizio, K.R., Tsolmon, U., 2014. An empirical examination of theprocyclicalityof R&D investment and innovation. Rev. Econ. Stat. 96, 662–675.

Fiksel, J., Polyviou, M., Croxton, K.L., Pettit, T.J., 2015. From risk to resilience: learning to deal with disruption. MIT Sloan Manag. Rev. 56, 79–86.

Fisher, M.L., 1997. What is the right supply chain for your product? Harv. Bus. Rev. 75 (2), 105–116.
Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., Walker, B., 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. AMBIO A J. Hum. Environ. 31, 437–440.
Gligor, D.M., Holcomb, M.C., 2012. Understanding the role of logistics capabilities in achieving supply chain agility: a systematic literature review. Supply Chain Manag.: Int. J. 17, 438–453.
Golgeci, I., Ponomarov, S.Y., 2013. Does firm innovativeness enable effective responses to supply chain disruptions? An empirical study. Supply Chain Manag.: Int. J. 18, 604–617.
Greening, P., Rutherford, C., 2011. Disruptions and supply networks: a multi-level, multi-theoretical relational perspective. Int. J. Logist. Manag. 22 (1), 104–126.
Griffith, R., Redding, S., Van Reenen, J., 2004. Mapping the two faces of R&D: productivity growth in a panel of OECD industries. Rev. Econ. Stat. 86 (4), 883–895.
Gu, M., Huo, B., 2017. The Impact of Supply Chain Resilience on Company Performance: A Dynamic Capability Perspective. Academy of Management Annual Meeting Proceedings, Atlanta, GA.
Hair Jr., J.F., Black, W.C., Babin, B.J., Anderson, R.E., 2010. Multivariate Data Analysis, seventh ed. Pearson.
Hall, B.H., Francesca, L., Mairessef, J., 2012. Evidence on the impact of R&D and ICT investments on innovation and productivity in Italian firms. Econ. Innovat. N. Technol. 1–29.
Helfat, C.E., Peteraf, M.A., 2003. The dynamic resource-based view: capability lifecycles. Strat. Manag. J. 24, 997–1010.
Hendricks, K.B., Singhal, V.R., 2005. An empirical analysis of the effect of supply chain disruptions on long-run stock price performance and equity risk of the firm. Prod. Oper. Manag. 14 (1), 35–52.
Herrgard, M.M., Rabe, A.P.J., Lo, S., Ragazzoni, L., Burkle Jr., F.M., 2017. Building resilience by professionalization of healthcare workers through technological innovation. Int. J. Disaster Risk Reduct. 22, 246–248.
Hu, L., Bentler, P.M., 1999. Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. Struct. Equ. Model. 6 (1), 1–55.
Hult, G.T.M., Hurley, R.F., Knight, G.A., 2004. Innovativeness: its antecedents and impact on business performance. Ind. Market. Manag. 33, 429–438.
Iacobucci, D., 2010. Structural equations modeling: fit indices, sample size, and advanced topics. J. Consum. Psychol. 20 (1), 90–98.
Johnson, M., Templar, S., 2011. The relationships between supply chain and firm performance: the development and testing of a unified proxy. Int. J. Phys. Distrib. Logist. Manag. 41, 88–103.
Jung, H., Hwang, J., Kim, B.K., 2018. Does R&D investment increase SME survival during a recession? Technol. Forecast. Soc. Change 137, 190–198.
Jüttner, U., Maklan, S., 2011. Supply chain resilience in the global financial crisis: an empirical study. Supply Chain Manag.: Int. J. 16, 246–259.
Jüttner, U., Peck, H., Christopher, M., 2003. Supply chain risk management: outlining an agenda for future research. Int. J. Logist. Manag. 6, 197–210.
Kamalahmadi, M., Parast, M.M., 2016. A review of the literature on the principles of enterprise and supply chain resilience: major findings and directions for future research. Int. J. Prod. Econ. 171, 116–133.
Kanter, R.M., 1983. The Change Masters: Innovation for Productivity in the American Corporation. Simon & Schuster, New York, NY.
Karlsson, M., Trygg, L., Elfsstrom, B., 2004. Measuring R&D productivity: complementing the picture by focusing on research activities. Technovation 24, 176–186.
Katkalo, V.S., Pitelis, C.N., Teece, D.J., 2010. Introduction: on the nature and scope of dynamic capabilities. Ind. Corp. Change 19, 1175–1186.
Kindström, D., Kowalkowski, C., Sandberg, E., 2013. Enabling service innovation: a dynamic capabilities approach. J. Bus. Res. 66, 1063–1073.
Knemeyer, A.M., Zinn, W., Eroglu, C., 2009. Proactive planning for catastrophic events in supply chains. J. Oper. Manag. 27, 141–153.
Krishnan, V., 2013. Operations management opportunities in technology commercialization and entrepreneurship. Prod. Oper. Manag. 22, 1439–1445.
Lee, C.-L., Wu, H.C., 2016. How do slack resources affect the relationship between R&D expenditures and firm performance? R&D Manag. 46, 958–978.
Lengnick-Hall, C.A., Beck, T.E., 2005. Adaptive fit versus robust transformation: how organizations respond to environmental change. J. Manag. 31, 738–757.
Lengnick-Hall, C.A., Beck, T.E., Lengnick-Hall, M.L., 2011. Developing a capacity for organizational resilience through strategic human resource management. Hum. Resour. Manag. Rev. 21, 243–255.
Lome, O., Heggeseth, A.G., Moen, O., 2016. The effect of R&D on performance: do R&D-intensive firms handle a financial crisis better? J. High Technol. Manag. Res. 27, 65–77.
Mainela, T., Puhakka, V., 2008. Embeddedness and networking as drivers in developing an international joint venture. Scand. J. Manag. 24, 17–32.
Markman, G.D., Gianiodis, P.T., Phan, P.H., 2009. Supply-side innovation and technology commercialization. J. Manag. Stud. 46, 625–649.
Melnyk, S.A., Closs, D.J., Griffis, S.E., Zobel, C.W., Macdonald, J.R., 2014. Understanding supply chain resilience. Supply Chain Manag. Rev. 18 (1), 34–41.
Mitroff, I.I., Alpaslan, M.C., 2003. Preparing for evil. Harv. Bus. Rev. 81, 109–115.
Narasimhan, R., Kim, S.W., Tan, K.C., 2008. An empirical investigation of supply chain strategy typologies and relationships to performance. Int. J. Prod. Res. 46 (18), 5231–5259.
Nooraie, V., Fathi, M., Narenji, M., Parast, M.M., Pardalos, P.M., Stanfield, P.M., 2019. A multi-objective model for risk mitigating in supply chain design. Int. J. Prod. Res. (in press).
Nunnally, J.C., Bernstein, I.H., 1994. The assessment of reliability. Psychom. Theor. 3, 248–292.
Parast, M.M., Spillan, J., 2014. Logistics and supply chain process integration as a source of competitive advantage: an empirical analysis. Int. J. Logist. Manag. 25 (2), 289–314.
Parast, M.M., Sabahi, S., Kamalahmadi, M., 2019. The relationship between firm resilience to supply chain disruptions and firm innovation. In: Revisiting Supply Chain Risk. Springer, Cham, pp. 279–298.
Patel, P.C., Guedes, M.J., Soares, N., Goncalves, V.D.C., 2018. Strength of the association between R&D volatility and firm growth: the role of corporate governance and tangible asset volatility. J. Bus. Res. 88, 282–288.
Pettigrew, A., Whipp, R., 1993. Managing the twin processes of competition and change – the role of intangible assets. In: Peter, L., Chakravarthy, B., Roos, J., Van de Ven, A. (Eds.), Implementing Strategic Processes: Change, Learning and Co-operation. Blackwell, Cambridge, UK, pp. 3–42.
Pitelis, C.N., Teece, D.J., 2010. Cross-border market co-creation, dynamic capabilities and the entrepreneurial theory of the multinational enterprise. Ind. Corp. Change 19, 1247–1270.
Podsakoff, P.M., MacKenzie, S.B., Lee, J.-Y., Podsakoff, N.P., 2003. Common method biases in behavioral research: a critical review of the literature and recommended remedies. J. Appl. Psychol. 88 (5), 879–903.
Ponomarov, S.Y., Holcomb, M.C., 2009. Understanding the concept of supply chain resilience. Int. J. Logist. Manag. 20, 124–143.
Pradabwong, J., Braziotis, C., Tannock, J.D.T., Pawar, K.S., 2017. Business process management and supply chain collaboration: effects on performance and competitiveness. Supply Chain Manag.: Int. J. 22 (2), 107–121.
Reinmoeller, P., Van Baardwijk, N., 2005. The link between diversity and resilience. MIT Sloan Manag. Rev. 46, 61–65.
Ren, S.J., Hu, C., Ngai, E.W.T., Zhou, M., 2015. An empirical analysis of inter-organisational value co-creation in a supply chain: a process perspective. Prod. Plann. Contr. 26 (12), 969–980.
Richtnér, A., Löfsten, H., 2014. Managing in turbulence: how the capacity for resilience influences creativity. R&D Manag. 44, 137–151.
Robertson, T.S., Gatignon, H., 1987. The diffusion of high technology innovations: a marketing perspective. In: Pennings, J.M., Buitendam, A. (Eds.), New Technology as Organizational Innovation. Ballinger, Cambridge, MA, pp. 179–196.
Romanelli, E., Tushman, M.L., 1994. Organizational transformation as punctuated equilibrium: an empirical test. Acad. Manag. J. 37, 1141–1666.
Sabahi, S., Parast, M.M., 2019. Firm innovation and supply chain resilience: a dynamic capability perspective. Int. J. Log. Syst. Appl. (in press).
Sabatino, M., 2016. Economic crisis and resilience: resilient capacity and competitiveness of the enterprises. J. Bus. Res. 69, 1924–1927.
Saint-Germain, R., 2005. Information security management best practice based on ISO/IEC 17799. Inf. Manag. J. 39 (4), 60–66.
Santiago, L.P., Bifano, T.G., 2005. Management of R&D projects under uncertainty: a multidimensional approach to managerial flexibility. IEEE Trans. Eng. Manag. 52 (2), 269–280.
Saren, M., 1987. The role of strategy in technological innovation: a re-assessment. In: Mangham, I.L. (Ed.), Organization Analysis and Development. Wiley, Chichester, UK, pp. 125–165.
Scherer, F.M., Ross, D., 1990. Industrial Market Structure and Economic Performance, third ed. Houghton Mifflin, Boston, MA.
Schweitzer, F., Fagiolo, G., Sornette, D., Vega-Redondo, F., Vespignani, A., White, D.R., 2009. Economic networks: the new challenges. Science 325, 422–425.
Shekarian, M., Nooraie, S.V.R., Parast, M.M., 2019. An examination of the impact of flexibility and agility on mitigating supply chain disruptions. Int. J. Prod. Econ. (in press).
Sher, P.J., Yang, P.Y., 2005. The effects of innovative capabilities and R&D clustering on firm performance: the evidence of Taiwan's semiconductor industry. Technovation 25 (1), 33–43.
Shin, N., Kraemer, K.L., Dedrick, J., 2017. R&D and firm performance in the semiconductor industry. Ind. Innovat. 24, 280–297.
Shishebori, D., Yousefi-Babadi, A., 2015. Robust and reliable medical services network design under uncertain environment and system disruptions. Transport. Res. E Logist. Transport. Rev. 77, 268–288.
Soni, U., Jain, V., Kumar, S., 2014. Measuring supply chain resilience using a deterministic modeling approach. Comput. Ind. Eng. 74, 11–25.
Stevens, E., Dimitriadis, S., 2004. New service development through the lens of organizational learning: evidence from longitudinal case studies. J. Bus. Res. 57, 1074–1084.
Su, H., Linderman, K., 2016. An empirical investigation in sustaining high-quality performance. Decis. Sci. J. 47, 787–819.
Sutcliffe, K.M., Vogus, T., 2003. Organizing for resilience. In: Cameron, K.S., Dutton, J.E., Quinn, R.E. (Eds.), Positive Organizational Scholarship: Foundations of A New Discipline. Berrett-Koehler, San Francisco, CA, pp. 94–110.
Teece, D.J., 2007. Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. Strat. Manag. J. 28, 1319–1350.
Teece, D.J., 2012. Dynamic capabilities: routines versus entrepreneurial action. J. Manag. Stud. 49, 1395–1401.
Teece, D.J., Pisano, G., Shuen, A., 1997. Dynamic capabilities and strategic management. Stratgeic Manag. J. 18 (7), 509–533.
Trkman, P., Štemberger, M.I., Jakli, J., Groznik, A., 2007. Process approach to supply chain integration. Supply Chain Manag.: Int. J. 12 (2), 116–128.
Tuominen, M., Rajala, A., Möller, K., 2004. How does adaptability drive firm innovativeness? J. Bus. Res. 57 (5), 495–506.

Tushman, M.L., O'Reilly III, C.A., 1996. Ambidextrous organizations: managing evolutionary and revolutionary change. Calif. Manag. Rev. 38, 8–30.
Uhlenbruck, K., Meyer, K.E., Hitt, M.A., 2003. Organizational transformation in transition economies: resource-based and organizational learning perspectives. J. Manag. Stud. 40, 257–282.
Un, C.A., Asakawa, K., 2015. Types of R&D collaborations and process innovation: the benefit of collaborating upstream in the knowledge chain. J. Prod. Innovat. Manag. 32 (1), 138–153.
Wagner, S.M., Bode, C., 2008. An examination of supply chain performance along several dimensions of risk. J. Bus. Logist. 29 (1), 307–325.
Walker, B., Gunderson, L.H., Kinzig, A., Folke, C., Carpenter, S., Schultz, L.A., 2006. A handful of heuristics and some propositions for understanding resilience in social-ecological systems. Ecol. Soc. 11 (1), 13.
Wang, C.L., Ahmed, P.K., 2007. Dynamic capabilities: a review and research agenda. Int. J. Manag. Rev. 9 (1), 31–51.
Wang, J., Yang, C.-Y., 2012. Flexibility planning for managing R&D projects under risk. Int. J. Prod. Econ. 135 (2), 823–831.
Weerawardena, J., Mavondo, F.T., 2011. Capabilities, innovation and competitive advantage. Ind. Market. Manag. 40, 1220–1223.
Welker, M., Ye, K., Zhang, N., 2017. (Un)intended consequences of a mandatory dividend payout regulation for earnings management: evidence from a natural experiment. J. Account. Audit Finance 32, 510–535.
Wildavsky, A., 1988. Searching for Safety. Transaction Books, New Brunswick, NJ.
Williams, T., Gruber, D., Sutcliffe, D., Shepherd, D., Zhao, E.Y., 2017. Organizational response to adversity: fusing crisis management and resilience research. Acad. Manag. Ann. 11, 733–769.
Winter, S.G., 2003. Understanding dynamic capabilities. Strat. Manag. J. 24, 991–995.
World Economic Forum, 2013. Global Risks 2013. Davos. World Economic Forum, Switzerland.
Wu, S.J., Melnyk, S.A., Flynn, B.B., 2010. Operational capabilities: the secret ingredient. Decis. Sci. J. 4, 721–754.
Xiao, T., Qi, X., 2008. Price competition, cost and demand disruptions and coordination of a supply chain with one manufacturer and two competing retailers. OMEGA 36 (5), 741–753.
Xu, C., Yan, M., 2014. Radical or incremental innovations: R&D investment around CEO retirement. J. Account. Audit Finance 29, 547–576.
Zsidisin, G.A., Panelli, A., Upton, R., 2000. Purchasing organization involvement in risk assessments, contingency plans, and risk management: an exploratory study. Supply Chain Manag.: Int. J. 4 (5), 187–198.