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Supply-side resilience as practice bundles: a critical incident study

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Abstract

Purpose – The purpose of this paper is to conceptualize a typology of supply-side resilience capabilities and empirically validates these capabilities and their constituent bundles of practices.

Design/methodology/approach – The study is primarily qualitative, employing the critical incident technique to collect data across 22 firms and seeking to validate how and why practice bundles form and relate to operations performance. It contains a frequency of occurrence analysis for the purpose of triangulation, a minor statistical part to provide some additional evidence of bundle formation and correlation between adoption of bundles of practices and recovered operations performance after upstream supply chain disruptions.

Findings – Four supply-side resilience capabilities are conceptualized along two dichotomous dimensions – "proactive/reactive" and "internal/external" – in a 2×2 matrix as proactive-internal, proactive-external, reactive-internal and reactive-external resilience capabilities. Empirical support for the conceptualized typology is found. Bundles of specific practices that can be associated with each capability are identified. Moreover, the study finds a relationship between these practice bundles and recovered operations performance.

Research limitations/implications – The statistical part is used just to provide some additional evidence through factor and regression analyses that these capabilities exist and do benefit adopting firms.

Practical implications – Specifies practices that lead to recovered operations performance in the event of supply disruptions.

Originality/value – Advances current theory by operationalizing resilience as a set of dynamic capabilities in terms of practice bundles that aid in recovering operations performance upon supply disruptions.

Keywords Supply chain resilience, Dynamic capabilities, Critical incident technique, Mixed-methods research, Bundles of practices, Operations performance

Paper type Research paper

1. Introduction

Upstream supply chain disruptions are becoming a major managerial problem for operations professionals (Autry *et al.*, 2013). Accordingly, there is increasing scholarly interest in how firms can develop capabilities to manage unanticipated changes along the supply chain (e.g. Ponomarov and Holcomb, 2009). Within the current resilience literature some conceptual frameworks exist describing what resilience entails in a business environment and characterizing it (Christopher and Peck, 2004;

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Craighead *et al.*, 2007; Sheffi and Rice, 2005). However, most existing frameworks are too abstract; detailed studies of what actually constitutes resilience capabilities are sparse.

This paper reports on a study that conceptualizes a typology of dynamic supply-side resilience capabilities. It then validates these capabilities and the practice bundles constituting them through empirical analysis. Practices are recognized as the building blocks of dynamic capabilities (Teece *et al.*, 1997). However, only recently have studies tried to connect the dynamic capabilities perspective to the bundles of practices idea of Shah and Ward (2003), enhancing operationalization and the practical implications (Peng *et al.*, 2008). Ketokivi and Schroeder (2004) have discussed how a firm's dynamic capabilities are embedded in its "routine" practices. To the best of our knowledge, attempts to operationalize resilience in terms of dynamic capabilities and practices are limited.

A key reason to fill this identified gap is that supply chain disruptions are having such a negative impact on business performance; firms must learn to recover quickly. For example, Hendricks and Singhal (2003) show that the long-run stock market reaction to supply disruption announcements is very negative; average abnormal returns after a disruption are reaching nearly −10 percent. Subsequent studies demonstrated that disruption announcements are associated with a significant drop in operating income, return on assets and return on sales (Hendricks and Singhal, 2005). These studies show that most firms are not recovering well and fast enough; more research is needed on accomplishing successful recovery.

Hence, our purpose is to conceptualize a typology of supply-side resilience capabilities and then validate these capabilities and their constituent bundles of practices through empirical examination. The underlying rationale is that research on supply-side resilience capabilities as bundles of practices can help to develop a deeper understanding for which actions to take, when and where, and how these practices support the recovery process.

Section 2 of this paper deduces a conceptualization of supply-side resilience as a set of dynamic capabilities consisting of practice bundles that recover operations performance in the event of disruption. Section 3 details our research methodology, consisting in using the critical incident technique (CIT) to collect empirical data and then combining qualitative and quantitative methods to triangulate results. Section 4 presents our findings. Strong empirical support was found for the conceptualization. After specific practices were identified and determined, these practices were found to form internally consistent, interrelated and complementary bundles that lead to recovered operations performance when buying firms face upstream disruptions. Section 5 discusses the value of our findings. In contrast to previous literature that mainly emphasizes logistics-based mitigation strategies, such as increasing capacity and inventory, we shift emphasis to organizational behavior routines. In particular, we link dynamic capabilities with the practice bundles literature. We conclude that supply-side resilience capabilities can be operationalized along the two dichotomous dimensions "proactive/reactive" and "internal/external" in a 2×2 matrix, and that they all positively influence the buying firm's manufacturing operations performance to recover after an upstream supply chain disruption.

2. Theory development

Supply-side resilience as dynamic capability

Supply-side resilience can be defined as the capability of a buying firm to prepare for, respond to and recover from unexpected upstream supply chain disruptions by returning to, or maintaining continuity of, operations at the desired level of connectedness and control over structure and function (Ponomarov and Holcomb, 2009). Disruptions in supply chains imply a phenomenon where one or more events taking place at one point in the supply chain adversely affect (or have the potential to affect) the operations performance of one or more members located elsewhere in the chain (Melnyk *et al.*, 2009).

Previous studies (e.g. Christopher and Peck, 2004) have typically conceptualized supply chain resilience as a property coming from accumulation of redundant capacity and inventory. These remedies come at considerable expense, yet they may not be free from risks that affect the integrity and functioning of the assets owned by an enterprise or any actor across the supply chain. Here we shift the focus of resilience in supply chains from redundant capacity and inventory to dynamic capabilities. Consistent with the definition of supply-side resilience we adopted, we argue that supply-side resilience can be conceptualized to consist of dynamic capabilities. A dynamic capability is "the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing circumstances" (Teece *et al.*, 1997). Capabilities for future use can be either created or refreshed from existing ones in changing circumstances (Teece *et al.*, 1997). These capabilities can enhance a firm's reconfiguration of existing infrastructure to better manage disruptions (Ambulkar *et al.*, 2015).

Resilience capabilities as bundles of practices

Dynamic capabilities are formed from intentional practices undertaken in the business firm (Zollo and Winter, 2002). Bundles of practices can serve to connect highly abstract concepts with measurable indicators. They allow easier organization of multifaceted abstract concepts like continuous improvement (Bessant *et al.*, 2001), Lean (Shah and Ward, 2003) and human resource management (Macduffie, 1995). In a similar fashion, supply-side resilience capability can be represented as bundles of practices, as we are showing in this paper. Our approach can be seen as an extension of the work of Peng *et al.* (2008) operationalizing dynamic capabilities as bundles consisting of logically interrelated practices (routines).

Formation of practice bundles must fulfill at least three criteria: the practices brought together must be internally consistent; the practice bundles must be interrelated; bundles must be complementary (Macduffie, 1995). That is, practices from two different bundles together provide synergistic effects that either one alone could not provide (Furlan *et al.*, 2011). Obtaining acceptable Cronbach's α values and factor loadings in a principal component analysis demonstrates the statistical equivalents of the first two criteria (Shah and Ward, 2003). The third criterion can be modeled as either an additive or a multiplicative effect (Macduffie, 1995).

The significant value in using practice bundles is that while a specific practice may vary, similarities are maintained at the bundle level. Following the logic of conceptualizing resilience as a dynamic capability and linking capabilities to practices through meaningful bundle formation (Peng *et al.*, 2008), we argue that resilience capabilities are essentially a set of practice bundles. This argument is in line with the study of Ketokivi and Schroeder (2004), who discuss how dynamic capabilities form from internally consistent practice routines. In addition, recent operations management literature suggests that the sources of competitive advantage are practices rather than the possession of assets per se (e.g. Ketokivi and Schroeder, 2004). Dynamic capabilities help to deploy the resources and infrastructure to align with prevailing circumstances upon disruption (Ambulkar *et al.*, 2015).

Practice bundles of supply-side resilience in two dimensions

Based on a review of relevant literature, we frame practice bundles of resilience along the following two main dimensions: proactive or reactive and internal or external.

Proactiveness in managing supply-side disruptions entails anticipating uncertainties and planning ahead for countermeasures (Craighead *et al.*, 2007; Grötsch *et al.*, 2013; Knemeyer *et al.*, 2009). The firm must also be able to react swiftly once disruptions happen (Craighead *et al.*, 2007; Rice and Caniato, 2003). Supply-side resilience capabilities can also be approached according to the capability's location. We approach this issue from the internal/external dichotomy. Internal means focus on practices within the boundaries of the buying firm for managing and mitigating risk sources, while external refers to practices related to the buying firm's capabilities to integrate and benefit from actions of actors in the wider supply chain network (Norrman and Jansson, 2004; Rice and Caniato, 2003).

Resilience practice bundles can be classified according to both dimensions at the same time. That is, a practice bundle can be proactive while focussing either on internal processes or external issues; the same holds true for reactive bundles. These bundles are represented as the four quadrants of Figure 1.

The different studies on resilience reviewed discuss resilience practices that can be positioned within the four types of resilience capability (practice bundles) shown in Figure 1. In Table I we present some of the practices explicitly mentioned in the literature as ways of having better resilience against disruption.

Table I reveals that most of the papers mention practices belonging to more than one practice bundle category. For example, Jüttner and Maklan (2011) mention that establishing long-term relationships with suppliers and customers enables fast recovery during a disruption, a process that must be set up before a disruptive incident happens and is therefore regarded as proactive. They also argue that coordination both within the firm and with other firms, together with fast dessimination of information, are relevant practices to do once disruptions happen (i.e. reactively). Rice and Caniato (2003) focus on proactive measures of resilience through improving the experience level of employees and enhancing opportunities to learn from past events and near misses. Learning from previous incidents for future preparedness is

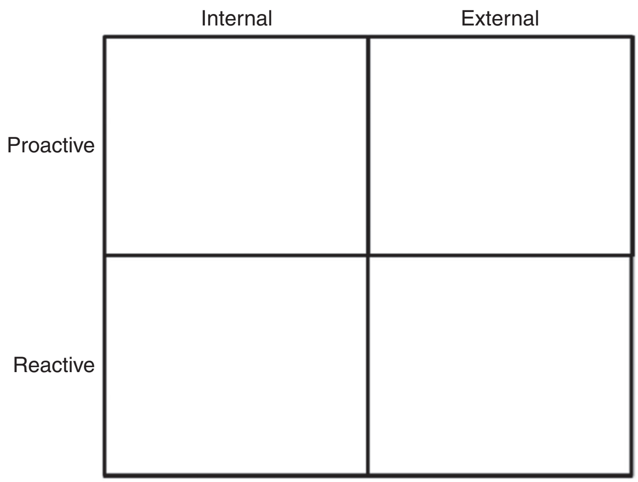

Figure 1. Resilience dimensions

Routines	Source P1	P2	P3	P4	P5	P6	P7	P8	P9
Proactive capability routines									
Internal									
Trained/experienced employees		X							
Learning from previous disruptions and near misses		X		X	X				X
Established recovery processes			X						
External									
Alternative sourcing bases						X	X		
Scanning environment for detection of symptoms of disruption			X						
Customer-supplier long-term relationship and cooperation	X	X	X				X		X
Reactive capability routines									
Internal									
Task force for recovery								X	
Clear identification of responsibility				X				X	
Coordination within a firm	X				X				X
Support from top management									X
External									
Coordination among firms	X				X	X			X
Information dissemination to relevant organization	X		X		X	X			X

Notes: P1, Jüttner and Maklan (2011); P2, Rice and Caniato (2003); P3, Sheffi and Rice (2005); P4, Hendricks and Singhal (2003); P5, Sheffi (2007); P6, Craighead *et al.* (2007); P7, Tang (2006); P8, Norrman and Jansson (2004); P9, Ponomarov and Holcomb (2009)

Table I. Resilience capabilities as evidenced in literature

also discussed by Sheffi and Rice (2005) and Sheffi (2007), with demonstrative case examples. Ponomarov and Holcomb (2009) discuss several proactive and reactive measures pertaining to both internal and external categories of practice bundles based on their review of resilience literature. Some example practices they discuss include buyer-supplier long-term relationships, support from top management, fast information dissemination and coordination among firms.

While the summary in Table I provides direction on possible practices, it is also rather fragmented. It does not tell to what extent practices can be combined into bundles or if these are the only practices relevant for attaining better resilience capability.

Propositions

From the theoretical discussion so far it follows that supply-side resilience can be framed as dynamic capabilities which consist of proactive-internal, proactive-external, reactive-internal and reactive-external bundles of possible practices. This suggests four independent variables, namely, proactive-internal, proactive-external, reactive-internal and reactive-external bundles of possible resilience practices. The specific practices are still to be identified in this study. As dependent variable, we suggest the buying firm's ability to return to its original or desired level of manufacturing operations performance after disruption by an unforeseen upstream supply chain incident. Operations performance objectives are usually referred to as quality, speed, dependability, flexibility and cost (Slack and Lewis, 2008). For assessing resilience, the key issue is the level of operations performance after recovery in areas that particular buying firm prioritizes among the performance objectives. Priority weights are used for this purpose, as suggested in Bozarth and Edwards (1997). If, for example, quality is highly important to win customer orders, that firm must obtain a highly satisfactory level on the quality performance objective.

Representative discussions on the relationship between resilience capabilities and recovery performance have been reported. For example, Craighead *et al.* (2007) expect proactive and reactive capabilities to have an inverse relationship with the potential severity of supply chain disruptions. The implication is that performance is more likely to return to a previous or more desired level immediately after major recovery efforts if proactive and reactive measures are in place. In the context of the present study, each of our four independent variables should cause a positive effect on our dependent variable.

For empirical verification of the theory, we formulated three study propositions, which we then subjected to empirical analysis in order to validate our theoretical development:

P1. Supply-side resilience can be operationalized as four distinct types of dynamic capabilities, namely, proactive-internal, proactive-external, reactive-internal and reactive-external. These four dynamic capabilities can be further operationalized as a set of internally consistent and interrelated bundles of practices.

P2a. Each of these four bundles of practices helps buying firms to recover their manufacturing operations performance to its original or desired state in the event of an upstream supply chain disruption.

P2b. Moreover, there are also complementarities among the bundles of practices leading to positive synergistic effects on buying firms' ability to recover manufacturing operations performance to its original or desired state in the event of a supply disruption.

3. Research methodology

Methodological overview and sampling procedure

To address the propositions posed, we utilized a sequential research approach including two interlinked CIT studies: first, a pre-study among 14 firms, and then, a main study among 22 other firms. The pre-study used a qualitative CIT approach to validate and possibly complement practices identified from literature. In the subsequent main study a qualitative and quantitative CIT approach was used in order to validate bundle formation as well as these bundles' impact on recovered operations performance. Our overall research approach is in line with the main steps Hensley (1999) suggests to generate items and constructs to build and test a mid-range theory in operations management.

CIT primarily focusses on incidents as references of inquiry (Chell, 2004; Flanagan, 1954). By focussing on an incident, the aim is to examine deviations and abnormal situations that can tell something about the behavior and characteristics of the system as a whole. The outcome of a critical incident is typically characterized as positive or negative in relation to the achievement of specific objectives (Chell, 2004). We decided to use CIT because we view upstream supply chain disruptions as critical incidents that impact the operations performance objectives, such as cost, quality, speed and flexibility, under investigation in this study.

The use of CIT in this study is important because of the retrospective nature of the incidents we analyze. Informants naturally tend to remember incidents that have significant impact on some objectives (Chell, 2004). Significant incidents yield a greater possibility to gain rich details about an organization's actions. Furthermore, the versatile nature of the approach (Chell, 2004) allows combining qualitative and quantitative research methods. The qualitative analysis ensures internal validity, for example, that identified bundles mirror important managerial practices, and moreover, that these particular practices improve recovered operations performance. The statistical analysis, on the other hand, shows evidence of bundle formation through confirmatory factor analysis (CFA) as well as strength of association between our bundles of practices and recovered operations performance. The use of statistical research methods also enables generalizing beyond our study sample, although precautions are warranted given our sampling procedures and limited sample sizes.

The sampling procedure in both the pre- and main studies was based on personal contact lists. In the pre-study we collaborated with Ernst and Young, a major auditing and management consultancy. We used their client database to find firms and key informants. All were large firms, listed on the Stockholm Stock Exchange (Nasdaq OMX), believed to have the access and motivation to invest substantial efforts into alleviating negative consequences from disruptions. Example firms in the sample are Astra Zeneca, Atlas Copco and SKF. In the main study we used our own contact lists, aiming to find firms other than those in the pre-study and increased variation in such aspects as plant size, product mix, production system and order-fulfillment practices. Example firms in the main study are Coca-Cola, Ericsson, Sony-Ericsson, Sandvik and Scania.

We stopped data collection after 22 incidents for two reasons. More significant nuances did not appear during interviews and a good coverage of variation was obtained in contextual factors such as plant size, product mix, production systems and order-fulfillment practices.

Approach in the pre-study phase and its outcome

The aim of the pre-study phase was to empirically identify a comprehensive list of practices firms undertake when facing disruption, and to validate and possibly extend the list of practices identified from literature (cf. Table I). Data were collected on actions taken in 14 firms before and after encountering a disruption. Through unstructured interviews with probing questions informants were asked to identify, describe and assess a disruptive event the company had encountered. They also had to discuss the firm's recovery as successful, adequate or inadequate given the disruptive circumstance faced. Questions probed to what extent the disrupted material flows had returned to their original or desired state while at the same time also considering human and financial resources spent to recover, time to recovery and customer market reactions.

The firms were randomly chosen, since there were no preset criteria for such aspects as how well they have succeeded in their recovery effects. Suitability of the firms for the study and occurrence of recent supply chain disruptions were checked by a short telephone survey prior to each interview. At least one informant in a management position related to purchasing/supply chain, operations or distribution/logistics was interviewed from each firm. The firms preferred to remain anonymous about the manufacturing sites affected and other incident details.

The interviews were conducted during spring 2009. They were transcribed, with practices coded and listed by frequency of occurrence in the analyzed critical incidents. Short-listing the most important practice indicators was done in a three-step process. First we listed practices performed by the firm upon encountering the disruption, a total of 45 unique practices. In the second step we mapped the identified 45 practices by frequency of occurrence in the firms. Third, we removed practices that were least mentioned by firms with successful recovery and practices that were more frequently mentioned by firms with inadequate recovery, leaving 14 practices relevant to a positive recovery outcome. Threshold values were set according to the following two rules: a practice was removed if it was not used in at least half of the incidents with successful recovery; a practice was removed if it was used in at least half of the incidents with inadequate recovery and also did not comply with rule no. 1. None of the final 14 practices was used among firms with inadequate recovery. Through this process we could identify the most important practices and exclude the rest.

Subsequently, we grouped the 14 practices as follows into the categories: proactive-internal (four items), proactive-external (three items), reactive-internal (four items) and reactive-external (three items), as shown in Table II. Previous studies justified classifying resilience capabilities in terms of proactive/reactive and internal/external bundles (cf. Table I). The most important outcome of this pre-study is our progression from a fragmented description of practices across several studies in Table I to just one synthesized description of resilience practices in Table II.

Approach in the main study

In response to the three study propositions, the aim of the main study was to assess how the practices identified in the pre-study form particular resilience practice bundles and how they relate (directly and synergistically) to operations performance after recovery. This was done using CIT through qualitative analysis, a frequency of occurrence analysis and a limited statistical analysis with the purpose of triangulating results.

Given the 14 practices identified in the pre-study, the interview protocol of the main study required informants to identify and describe a specific disruption, as well as rate the practices identified in the pre-study and how they were used in the specific case (cf. Table II, last column). The questions were both open-ended and in a seven-point Likert scale format, to allow for richness and enable application of qualitative and quantitative research methods. Thus, every interview resulted in a transcribed incident summary as well as values on seven-point scales. The incident summaries described what happened at the incident scene, which practices were particularly crucial and their impact on operations performance.

Interviews took two to three hours and were conducted face-to-face, except for a few telephone interviews. Informants from each firm discussed only one critical incident from the two years preceding the interview date. These interviews were conducted in fall 2011. Informants were selected based on their direct involvement during a disruptive incident and related recovery efforts. They held management positions related to supply chain, logistics, purchasing, marketing, or production operations functions, depending on the particular firm's structure.

Overall, the incidents investigated in this paper concentrate around natural, manmade and economic causes that halted or delayed production or delivery of products. Earthquake and flooding at a major supplier's facility were examples of natural causes. Economic circumstances included supplier bankruptcy (without prior notice) and illiquidity problems. Fire in a supplier's facility was another significant disruptive event. Other incident types included industrial accidents that damaged components, IT system crashes and malfunctioning components in complex industrial products. We summarized the 22 incidents according to the supply chain risk causes Chopra and Sodhi (2004) discussed and categorized. Table III shows distribution of the incidents on the basis of main risk drivers leading to disruption of the operations at the buying firm. Production and IT system risks triggered one-third of the incidents we investigated. Poor quality,

Bundles	Description	Indicators (practices)	
PROACTIVE_INTERNAL (PRO_IN)	Set of actions internal to the firm, introduced before a particular incident to prepare for recovery	Pro_In1	Plans for communication are developed prior to the incident occurs that help people understand what, with whom, how and when to communicate in the recovery process
		Pro_In2	People with experience of previous incidents (real or through management exercises) are appointed beforehand to handle incidents
		Pro_In3	Scenario planning and crisis management exercises take place before the incident occurs
		Pro_In4	A pre-incident systematic recovery process to solve unforeseen incidents is implemented
PROACTIVE_EXTERNAL (PRO_EX)	Set of actions introduced before a particular incident, focussed on the broader supply chain actors to leverage better recovery	Pro_Ex1	The surrounding environment is scanned beforehand for signals of possible disruptive events
		Pro_Ex2	Alternative suppliers are mapped in anticipation of possible disruptive events
		Pro_Ex3	Pre-incident, close supplier relationships based on trust are developed with key partners
REACTIVE_INTERNAL (REA_IN)	Set of actions done during or after an incident (reactive) and mainly used to build capabilities within a firm	Rea_In1	Managers are actively involved and support the recovery process through allocation of time, money, space and other resources
		Rea_In2	Task forces make use of a systematic recovery process to solve problems
		Rea_In3	Responsibility for different parts of the recovery process is distributed clearly and appropriately
		Rea_In4	People cooperate effectively in the recovery work through internal coordination across internal functions (e.g. in cross-functional task forces) as well as in their own areas

(*continued*)

Table II.
Practice bundles and underlying indicators

Bundles	Description	Indicators (practices)	
REACTIVE_EXTERNAL (REA_EX)	Set of reactive actions intended to build relationships and benefit from capabilities in the wider supply chain	Rea_Ex1	The organization collects information from the incident site with its own representatives
		Rea_Ex2	Relevant functions of the focal firm as well as key actors along the supply chain are informed fast
		Rea_Ex3	The focal firm collaborates effectively (e.g. sharing knowledge and resources) with external actors in the recovery process

Table II.

Category	Risk drivers (incident no.)	Total count
Disruptions	Natural disaster, war, terrorism, fire (2, 14, 20, 21) Labor disputes Supplier bankruptcy (8)	5
Delays	High-capacity utilization at supply source (9) Inflexibility of supply source Poor quality or yield at supply source (3, 7, 11, 12)	5
Systems risk	Information [or other] infrastructure breakdown (4, 5, 6, 15, 16, 17, 18, 22) System integration or extent of systems being networked	8
Forecast risk	Inaccurate forecasts due to long lead times, seasonality, product variety, short life cycles, small customer base (13) Information distortion	1
Procurement risk	Exchange-rate risk Price of inputs Fraction purchased from a single source (10, 19) Industry-wide capacity utilization (1)	3
Total		22

Notes: The classification was suggested by Chopra and Sodhi (2004). No incidents were reported in the following categories: intellectual property risk, receivables risk, inventory risk, capacity risk. The incident numbers correspond to the list in Table IV

Table III. Classification of disruption incidents according to risk categories

natural disaster and fire leading to delays and disruptions at the supply base accounted for the second most common causes. No incidents in this study were triggered by drivers related to intellectual property, receivables or capacity risk categories.

4. Results of the main study

Results of the qualitative data analysis

The transcribed incident summaries were used for the qualitative data analysis. The within-incident analyses showed which practices played a more significant role and how these practices led to improved operations performance in each specific case. The cross-incident analysis shows the aggregate pattern of adopted practices across all 22 incidents. Table IV briefly summarizes the incidents.

Table IV.
Brief summary of critical incidents

No.	Main product line	FTE	Incident description and duration in weeks (W)	Major organizational actions and related performance consequences at recovery
1	Food processing equipment	4,080	Lack of components due to increased business (38W)	Top management support and relationship with the supplier led to improved speed performance at recovery (other objectives remained the same). Informant believes that recovery time could have been shorter had they implemented other actions
2	Telecom equipment	90,260	Earthquake in Japan, several suppliers affected (13W)	With a strong supplier relationship, structured recovery work and top management support, the firm improved quality and flexibility objectives back to the level before the incident
3	Cosmetics and pharmaceuticals	100	Abnormal smell in a cosmetic item leading to customer safety concerns (2W)	Communication competence, structured recovery work and experienced employees led to speed and cost improved back to a level before the incident; informant perceived it as a highly satisfactory recovery
4	Light to heavy vehicles	8,000	Major delay due to process failure at a supplier (9W)	Communication competence, experienced employees, process for recovery and external collaboration helped to keep performance objectives at the same level throughout
5	Light to heavy vehicles	30	Malfunction of processes at a supplier due to failed change in IT system (52W)	Supplier relationship, structured recovery process and external coordination helped to improve speed, dependability, flexibility back to the pre-incident level. Recovery was considered highly satisfactory
6	Beverages	850	Power blackout (1W)	Structured recovery process, communication competence, process for recovery helped to retain same level of quality and dependability; speed and cost improved to a higher level
7	Light to heavy vehicles	160	Wrongly assembled parts from supplier due to miscommunication (1W)	Experience from previous incidents and mapping alternative suppliers before incident to maintain flexibility at a high level; speed, dependability, cost improved back to the pre-incident level
8	Control system products	200	Financial crisis led to under-production at supplier, causing major shortage (113W)	Specific project organization and external collaboration enabled improving cost and flexibility back to a high level. Informant feels recovery could have been better if proactive measures were taken too
9	IR camera	3,200	Supplier could not meet steep increases in demand (35W)	External collaboration (and support) enabled to maintain quality at high level; speed, dependability and cost improved back to the pre-incident level
10	Industrial machinery	50	Shortage because supplier prioritized serving others during capacity limitation (52W)	Structured recovery work, process for recovery, specific and clear project organization for recovery caused flexibility, cost and speed to improve back to the pre-incident level. Informant perceived the recovery as partly successful
11	Computer hardware	30	A supplier delivered unusable parts due to not following technical instructions (2W)	Informing the relevant organization fast and having experienced employees helped to improve speed and dependability back to the pre-incident level

(*continued*)

No.	Main product line	FTE	Incident description and duration in weeks (W)	Major organizational actions and related performance consequences at recovery
12	Chemicals and paint	290	Microbiological growth in raw material from a supplier (4W)	Process for recovery, support from top management and mapping alternative suppliers helped in improving quality and dependability back to the pre-incident level
13	Fruit juice	300	Low forecast, increased demand and transportation delay led to shortage (1W)	Communication competence with clear distribution of responsibility, informing relevant organization quickly, and experience from previous incidents helped to improve speed, dependability, flexibility and cost after recovery; perceived as satisfactory recovery
14	Pattern generators for IC chips	560	Tsunami in Japan 2011 that affected major supplier(s) (28W)	Having process for recovery, specific project organization, experienced employees, man at the incident site and informing the relevant organization quickly improved cost back to the pre-incident level; speed improved further. It was perceived as a satisfactory and fast recovery
15	Light to heavy vehicles	35,510	Broken bottleneck machinery of a supplier (15W)	Support from top management and structured recovery work helped cost to improve back to the pre-incident level, while other performance priorities remained the same
16	Control systems	34,900	Test equipment at a manufacturer broke down, which halted operations (22W)	Internal and external coordination, structured recovery work, and top management support led to improved speed of recovery
17	Industrial equipment	400	Machine failure at subcontractor (1W)	Specific project organization, support from top management and experienced employees led to improving cost and flexibility back to the pre-incident level
18	Beverages	170	Machine failure at supplier (2W)	Process and structured approach for recovery improved speed and flexibility
19	Heating system components	60	Change of supplier resulted in legal issues and disruption in manufacturing (22W)	Support from top management and clear distribution of responsibility helped to improve speed, dependability and cost somewhat. Informant feels the recovery was not quite satisfactory
20	Consumer electronics	9,160	Earthquake/tsunami in Japan that affected several suppliers (20W)	Informing organization fast, support from top management, specific project organization and process for recovery along with other actions helped to improve flexibility, cost and dependability somewhat
21	Processed fresh food	20	Fire damaged deliveries at a warehouse of a logistic service provider (2W)	Having specific project organization, man at the incident site and experienced employees contributed to improving cost, flexibility and speed
22	Metal manufacturing	3,000	Power interruption due to shortage of replacement fuses (1W)	Relationship with other supply chain actors before incident and support from top management helped to improve costs while maintaining the same performance level for other priorities throughout

Note: FTE, full-time equivalents

Table IV.

The qualitative data analysis shows that certain individual practices play a more significant role in each incident. At an aggregate level across all incidents, all the 14 practices play a significant role. Moreover, it is rarely the case that all practices that constitute a specific bundle are emphasized and play a significant role in one incident. Yet on an aggregate level, across all incidents, the practice bundles are maintained. The analysis also shows that practices from different bundles are usually used in every incident, which means that the four practice bundles are interrelated. Lastly, the analysis shows that constituent practices lead to improved operations performance in the event of a supply-side disruption. Although all operations performance objectives are rarely affected in one firm, the most prioritized ones usually are.

Results of frequency of occurrence analysis

The frequency of occurrence analysis is based on the Likert scale data and reported in Figures 2-3. We performed it to show that the practices consistently form the respective practice bundles, that the bundles are interrelated and that these lead (directly and synergistically) to recovered operations performance.

We first identified the firms that used a pair of practices in each bundle (i.e. scoring of 4 or more on the Likert scale corresponding to both practices making up the pair). Results of this are illustrated by the solid arrows within each box representing the bundles in Figure 2. The relative strength of using a pair of practices (i.e. number of firms using the pairs simultaneously) is shown by the number on the arrows. For example, 20 firms used internal coordination for problem solving (Rea_In4), assisted by active support from top

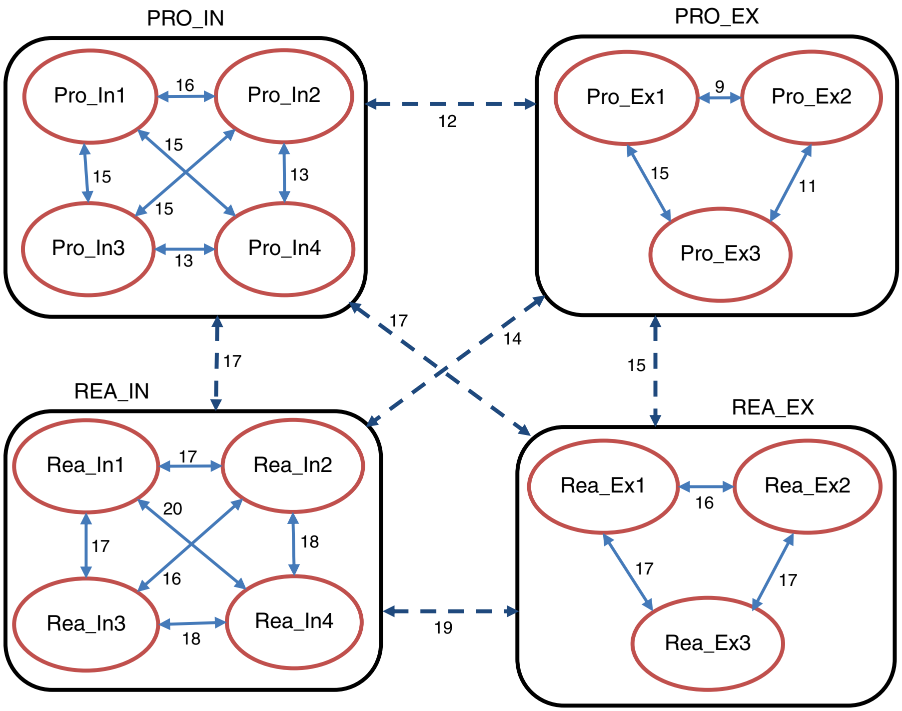

Figure 2.
The numerals beside the arrows show the number of firms applying at least a pair of practice bundles (solid arrows) and practices with a bundle (dotted arrows)

management (Rea_In1). The least used pair is the knowledge of the surrounding business environment (Pro_Ex1) with scouting out alternative supply bases before the incident (Pro_Ex2). The idea behind this diagram is that if firms use those practices together, they must have internal consistency. From this figure we can also see that firms have used a different number of practices from each bundle depending on the prevailing circumstances they faced and availability of resources during that particular incident. Although Figure 2 presents pairwise comparisons, we noted that the number of practices simultaneously used in most firms is often more than two. Not all firms necessarily used every practice listed in the practice bundles in equal intensity.

Overall, the practice bundles themselves are interrelated too. Therefore, we also present the strength of relationship among each practice bundle in Figure 2 using dotted arrows connecting boxes representing the bundles. The numbers on the arrows illustrate the number of firms that applied a pair of practice bundles during the incidents. The average of the ratings for practices in each bundle (⩾ 4.0 of 7.0 maximum possible) is considered for this illustration. As an example, 17 firms used at least a pair of proactive-internal and reactive-internal bundles of practices.

After observing the distribution of practices employed by the firms, we can evaluate how the five operations performance priorities have been affected by undertaking the practice bundles that form resilience capabilities. After a disruptive incident occurs and some recovery efforts have begun, there are three possible outcomes to performance objectives: they deteriorate, remain the same or improve relative to a reference just before the incident. Figure 3 shows the number of firms that managed to maintain or improve at least one performance objective by applying each practice bundle. In total, 15 firms managed to improve or maintain the same level of at least one performance objective by using proactive-internal resilience capabilities. In total, 11 firms that applied proactive-external capabilities maintained or improved one or more performance objectives. And 16 firms managed to maintain or improve at least one of their prioritized objectives by using reactive-internal and reactive-external capabilities, respectively.

When the marginal return to one activity increases by increasing the intensity of another, synergetic effects result (Furlan *et al.*, 2011). We find indications of synergistic effects in our sample. For example, the average level of performance improvement for firms who have high implementation of both "internal reactive" and "external reactive" bundles is higher than for firms with only one of the bundles high and the other low. Similar patterns of results are assured for most pairs as well as for triple and quadruple

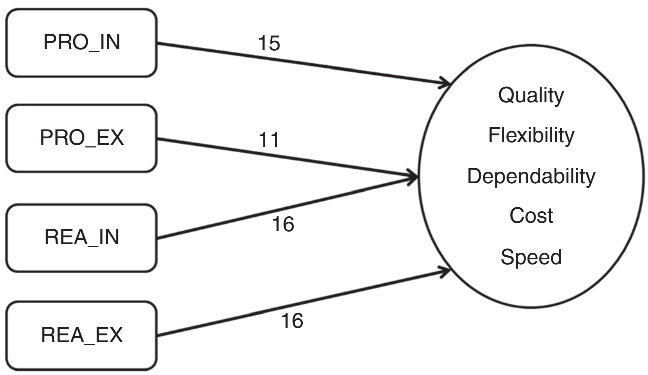

Figure 3.
Number of firms that maintained or improved at least one performance priority

bundles considered together. However, this analysis is more of an ocular inspection of data. Real comparison of differences in mean values requires a formal statistical test, provided in the next section.

Results from the statistical analysis

In this section we present findings from the statistical analyses of the seven-point Likert scale data. CFA was used to test if the classification of practices into meaningful bundles earlier proposed is valid. Moreover, regression analysis was used to estimate the strength of relationship among each of the independent variables (resilience capability bundles) and the dependent variable (performance after recovery). Regression was also used to test for complementarity, that is, to what extent there are synergistic effects of practice bundles adoption. Finally, statistical power analysis was used to check how reliably the regression analysis results can be used to draw meaningful conclusions with the given sample size.

The CFA results show that the practices grouped under the four resilience bundles seem to belong there, as can be seen in Table V. The majority of the factor loading values are well above the recommended value of 0.5 for acceptable factor analysis reliability (Hair *et al.*, 2009).

We tested for common method variance (CMV) using the CFA marker technique. In this technique all the items in the factor analyses are forced to extract only one factor in SPSS. The results show that the factor so identified explains less than 50 percent of the variance, indicating that CMV is acceptably small.

Cronbach's α values of 0.81, 0.54, 0.80 and 0.71 for the four resilience bundles indicate an acceptable factor reliability and internal consistency, given that the analysis was made using a newly developed scale and small sample size (cf. Table V). Cronbach's $\alpha \geqslant 0.70$ is usually recommended for established scales, while values higher than 0.60 are recommended for exploratory work and with newly developed scales (Flynn *et al.*, 1990), which is the case in this study. Values between 0.5 and 0.6 are conventionally considered poor but still not unacceptable for new scales.

In an attempt to extract a single recovery performance indicator (dependent variable) from the five performance objectives, the approach of Bozarth and Edwards (1997) was adopted. This involves multiplying the performance level of each objective criterion, *PERFi*, by its priority weight *IMPORTi*, and dividing by the sum of objective weights to reach a weighted average performance after recovery (*RECOV*) as given in the following equation:

$$RECOV = \frac{\sum_{i=1}^{5} PERF_i \times IMPORT_i}{\sum_{i=1}^{5} IMPORT_i} \tag{1}$$

Table V.
Factor analysis: actions in each factor and factor loadings

PROACTIVE_INTERNAL		PROACTIVE_ EXTERNAL		REACTIVE_ INTERNAL		REACTIVE_ EXTERNAL	
Pro_In3	0.94	Pro_Ex1	0.85	Rea_In4	0.86	Rea_Ex3	0.86
Pro_In2	0.89	Pro_Ex2	0.74	Rea_In2	0.81	Rea_Ex1	0.85
Pro_In1	0.75	Pro_Ex3	0.57	Rea_In3	0.76	Rea_Ex2	0.70
Pro_In4	0.58			Rea_In1	0.72		
No. of items per factor = 4		3		4		3	
Cronbach's α = 0.81		0.54		0.80		0.71	

Proceeding to the regression analysis, we opted to run three separate models, taking one independent variable at a time, predicting the dependent variable to be in line with our proposition. The reason for choosing to run simple regression rather than multiple regression is the strong correlation among the independent variables (Pearson correlation values of about 0.5-0.6, significant at $p < 0.05$). All capability bundles are significantly positively related to operations performance after recovery. The standardized coefficient (β) values for proactive-internal (model 1), proactive-external (model 2), reactive-internal (model 3) and reactive-external (model 4) bundles in respective order with their level of significance are: 0.61 ($p < 0.01$), 0.41 ($p < 0.05$), 0.36 ($p < 0.05$) and 0.38 ($p < 0.05$). Corresponding adjusted R^2 values of the models are 0.34, 0.13, 0.09 and 0.11.

Our initially stated propositions also suggest complementarities. Practice bundles are complementary if the total effect on operations performance of adopting two or more practice bundles simultaneously is higher than the sum of each part. We subjected the data to the procedure recommended in Lokshin *et al.* (2007) for testing complementarity among multiple practice bundles.

Test results based on our data show that two out of the four inequalities are satisfied. Since the minimum conditions of a formal complementarity test are fulfilled, it is an indication that the practice bundles have some complementarity among them[1].

The firms considered in the regression analysis were at different performance levels before the incident (initial condition). Using initial performance condition as control variable in all the regression analyses did not yield any significant change in the positive relationship the predictor variables had on the dependent variable. Therefore, regardless of performance priorities and performance levels before the incident, capabilities represented by the four practice bundles help to ensure better operations performance after recovery.

Ex post statistical power was also assessed for the four regression models to show that the significant values of regression coefficients are reasonably likely given the sample size. The results show that the sample size used, though seemingly small, is acceptably large to allow reasonable interpretations. According to the classification by Verma and Goodale (1995), a statistical power ($1-\beta$) of greater than 0.8 is considered high, and a value between 0.6 and 0.8 is considered of medium power. Statistical inferences from sample sizes that allow at least medium statistical power are considered acceptable. The powers obtained in the four regression models, taking their corresponding effect sizes (R^2), sample size, and confidence level (α) values as input, are as follows; model 1: 0.97; model 2: 0.66; model 3: 0.54; and model 4: 0.60. Thus, model 1 provides high statistical power, whereas models 2 and 4 provide a medium level. The value for model 3 indicates a need for caution, as it provides only 54 percent probability that the obtained significant relationship between reactive-internal and performance after recovery is not just chance.

Summary of results

We find strong empirical support for our typology of supply-side resilience practice bundles. Four supply-side resilience practice bundles were conceptualized along the two dichotomous dimensions "proactive or reactive" and "internal or external" in a 2×2 matrix as proactive-internal, proactive-external, reactive-internal and reactive-external resilience capabilities.

P1 concerns the actual formation of practice bundles. Step one of the main study yielded 14 relevant practices in the 22 critical incidents. Within and cross-incident analyses show that while particular incidents play a more significant role in individual incidents, the significance of all 14 is maintained on an aggregate level considering all 22 incidents. Furthermore, the frequency of occurrence analysis shows evidence that the 14 constituent practices form internally consistent and interrelated bundles of practices. Lastly, we found evidence of construct validity and reliability regarding our conceptualized typology and its constituent practices through CFA.

P2a concerns the relationship between the four types of supply-side resilience capabilities and operations performance in the event of supply disruptions. The qualitative data analysis clearly shows that the four types of resilience capabilities cause operations performance to recover to a desired level after being disrupted by an upstream supply chain incident. Different performance objectives are affected across the 22 studied incidents, but on an aggregate level the study shows that all four supply-side resilience bundles lead to mitigated operational performance in all five dimensions (cost, quality, speed, delivery and flexibility). The frequency of occurrence analysis shows additional evidence that each type of supply-side resilience capability leads to improved operations performance in prioritized performance dimensions. Lastly, the statistical data analysis shows evidence of the strength of relationship between each of the bundles of practices and operations performance. Each of the standardized regression coefficients is significant on at least the 5 percent level and in the range of 0.38-0.61, which is considered very strong evidence.

P2b concerns complementarities among the bundles of practices leading to positive synergistic effects on buying firms' ability to recover manufacturing operations performance. The frequency of occurrence analysis shows that adopting more bundles of practices leads to increasing levels of recovery performance. That is, adopting pairs, triple or quadruple bundles is associated with increasingly higher levels of performance. Lastly, the formal statistical test of complementarities is also an indication that the practice bundles have some synergistic performance effects, which helps to triangulate results.

5. Discussion

Prior to drawing conclusions, we discuss our findings in relation to the existing resilience literature. The discussion is structured according to the propositions formulated at the outset of this study, that is, operationalizing resilience as practice bundles, as well as, the impact of these practice bundles on operations performance.

Operationalizing resilience as practice bundles

Proactive and reactive resilience measures improve resilience in business firms (see, e.g. Grötsch *et al.*, 2013; Jüttner and Maklan, 2011; Sheffi and Rice, 2005; Sheffi, 2007). We extend this thought to an operations level by first proposing a two-dimensional typology for building resilience capabilities and then identifying and validating their constituent practice bundles. We carried out the actual validation in three steps, combining qualitative and quantitative research methods. The qualitative part ensures that the practices are used in industry but also further our understanding regarding idiosyncrasies that the practice bundles possess, for example, that firms can employ similar practices in a bundle differently and dynamically for varying unpredictable and complex circumstances (Pandža *et al.*, 2003). The quantitative part adds frequency counts and statistics ensuring that the four suggested practice bundles are internally consistent overall (pertaining to reliability) and interrelated (pertaining to construct validity). Thus, the functionality of resilience capabilities can be duplicated across firms (Eisenhardt and Martin, 2000), yet aspects of how specific practices are executed exhibit subtle differences (Ambrosini *et al.*, 2009), remaining unique to the firm with potential for superior competitive advantages.

Moreover, a recent study by Ambulkar *et al.* (2015) concludes that to build resilience against high-impact disruptions (in contrast to low-impact ones) requires a capability to "actively manage and reconfigure" resources. Our study identifies the bundles of practices that form such resilience capability. Besides, practices that we have identified are in concert with Matsuo's (2015) recent in-depth case description of Toyota's handling of the Tohoku earthquake, which strengthens the validity of our findings even more.

Impact of resilience practice bundles on operations performance after recovery

Several studies provide conceptual discussions with claims that higher resilience capabilities help to foster recovery activities in case of disruptions (e.g. Craighead *et al.*, 2007). However, empirical investigation and validation of such relationships is sparse. We believe that our study supports and furthers previous conceptual contributions on the link between resilience capabilities and improved operations performance after recovery through primary data from practitioners. Evidence for our claim comes from thorough qualitative investigation with methodological triangulation using quantitative analysis. The value of using mixed-methods research in this study is that it has helped to ascertain that these practice bundles really cause operations performance to recover (internal validity through qualitative research) as well as to estimate the strength of these relationships (external validity through quantitative research) which must be considered high and significant.

An interesting aspect seen from studying the standardized regression coefficients in detail is that the influence of the proactive-internal and proactive-external resilience practice bundles on recovery performance is much stronger than the reactive ones. This implies that firms could benefit from exercising proactive approaches rather than just working on post-incident recovery efforts. This is consistent with recent findings of supply chain risk management studies that underline the strong contribution of being proactive in managing supply chain disruptions (Grötsch *et al.*, 2013). It is also in line with a recent study by Chopra and Sodhi (2014) who show that undervaluing or ignoring unanticipated disruptions leads to higher long-term costs than overestimating.

Figure 4 attempts to illustrate and summarize the main takeaway from this study. It shows that that supply-side resilience capability can be operationalized along the two dichotomous dimensions "proactive or reactive" and "internal or external."

Figure 4 also illustrates that each of these capabilities is made of bundles of practices. Typical proactive-internal practices, for example, include that organizations develop plans for how to communicate, establish a systematic process for how to handle supply disruptions, and train employees in how to handle supply disruptions in anticipation of future incidents. Constituent proactive-external practices include, for example, that the organization scans the surrounding environment for signals of possible disruptive events, scouts out alternative suppliers and develops good relationships based on trust with current suppliers in anticipation of future supply-side disruptions. Reactive-internal practices include top management supporting the recovery effort, using a systematic process for recovery work, and distributing and coordinating responsibility for different problem solving and recovery actions clearly. Constituent reactive-external practices include, for example, that information is collected from the incident scene, that other relevant actors are informed rapidly, and that the buying firm collaborates effectively across the supply chain with other actors.

	Internal	External
Proactive	• A plan for crisis communication is established • A systematic process for handling unforeseen supply disruptions is established • People with earlier experience of handling supply disruptions are appointed • Scenario-based crisis management exercises are regularly undertaken	• The surrounding environment is regularly scanned for signals of possible disruptive events • Alternative suppliers are identified in the event of a possible supply disruption • Supplier relationships based on trust and partnership are developed in anticipation of supply disruptions
Reactive	• Managers are actively involved and support the recovery process through allocation of resources • Task forces make use of a systematic recovery process to solve problems • Responsibility for different parts of the recovery process is distributed clearly and appropriately • People cooperate	• The buying firm collects information from the incident site through its own representatives • Relevant functions of the buying firm as well as key actors along the supply chain are informed fast • The buying firm collaborates effectively (e.g. sharing knowledge and resources) with external actors in the recovery process

Figure 4.
Resilience dimensions with identified practice bundles

6. Conclusion

We conclude that supply-side resilience capability can be operationalized along the two dichotomous dimensions "proactive/reactive" and "internal/external" in a 2×2 matrix. Accordingly, the study finds four supply-side resilience capabilities: proactive-internal, proactive-external, reactive-internal and reactive-external. Moreover, all four of these resilience capabilities positively influence buying firms' manufacturing operations performance in recovery after an upstream supply chain disruption. This impact on operations performance is both direct and synergistic as a consequence of the complementarities among the four identified resilience capabilities.

Our findings complement past research that mainly emphasized redundant capacity and excess inventory as the approach to achieve resilience. Not all firms can afford the luxury of redundant capacity and excess inventory, and moreover it fits badly with Lean, which currently is the dominant paradigm. But firms can change organizational routines through implementation of new practices. To be fair, however, our study is not the only one advocating organizational practices. As we showed in our literature review, others before us have also identified certain practices – but this literature is rather fragmented. We therefore synthesize this literature and conceptualize underlying practices in time (proactive vs reactive) and space (internal vs external). Moreover, we amend and validate our conceptualization and constituent practices through empirical investigation.

This paper contributes to knowledge by adding a practice-based view. In particular, we advance current theory by showing how resilience can be operationalized as a set of dynamic capabilities in terms of practice bundles that recover operations performance.

This study has shown through conceptual work and empirical validation which practices are most relevant, how they bundle and how these bundles lead to improved operational performance in the event of an upstream supply chain disruption. The managerial problem addressed is of great importance to a large and increasing number of manufacturing firms, due to industry trends such as global sourcing, growing scarcities of natural resources, and congestion and infrastructure decay. Our contribution is also of value in that it undertakes mixed-methods research, which in this study helps to assure internal and external validity of research findings.

As with all studies, this one is not without limitations. The first one is the relatively small sample size of the statistical analysis compared to common survey methodologies. Even though we have shown that the computations are good enough to serve as auxiliary statistical evidence, a larger sample size would have helped pursue more granular analyses and also control for contextual factors. The small sample size might also have contributed to the small Cronbach's α value for one of the practice bundles. The second limitation is the seemingly different sampling criteria used in the pre- and main studies. However, in both instances the prime objective was to identify firms that had experienced different kinds of upstream supply chain disruptions, not to find a representative sample of firms as in common survey methodologies. When taking sample firm demographics into consideration we see that the main study represents a large variation in plant size, product mix, production systems and order-fulfillment practices. The third limitation is related to the deficiencies of recalling information. In conducting a retrospective study, we cannot avoid some level of "filtered" data presentation by informants, especially a challenge with a single informant for each incident. We believe, however, that the use of a pre-study prior to the main study as well as mixed-methods research reduces the effects of such bias. A fourth limitation is the time span of some of the included incidents. Eight incidents had a time span of two or fewer weeks. Some readers might think that such a short time event should not be considered as a disruption requiring resilience capabilities. The major reason to include these seemingly short incidents is the severity of consequences regardless of time span. These incidents had highly negative consequences on operation performance, for example, in process industry type of firms, with high value density. Last, a fifth possible limitation concerns how this study's findings pass the test of time, since data for the main study was collected during fall 2011. We think our findings are still highly relevant. Matsuo's (2015) recent single case study analyses the same Tohoku earthquake as in our sample, which shows the significance of publishing such data. Moreover, we believe these practice bundles are stable and will be of interest both to research and in practice. A relevant comparison is the work of Shah and Ward (2003) and still widely cited today. While our practice bundles per se are interesting, the most important contribution to knowledge, however, is how we advance current theory by showing how resilience can be operationalized as a set of dynamic capabilities in terms of practice bundles that recover operations performance. This contribution should be relevant for many years to come.

Nevertheless, the main research implication that follows from our operationalization is that we have laid a foundation for further research in the area. Practice-based supply chain resilience research is still in the birth phase of the research idea life cycle. Therefore, this study has had to develop constructs and a mid-range explanatory model, and we have restricted ourselves to testing direct and synergistic effects. As this research stream potentially moves into a growth phase, our constructs and model can be used as a stepping stone to investigate more complex research questions and models, such as those involving moderation and mediation effects. One possibility for further research in this vein could, for example, be to combine a bundle-of-practices-based approach with more structural decision areas, since this study has concentrated on organizational practices, whereas previous research in the area has mostly emphasized structural logistics-based decision areas such as capacity and inventory strategies to mitigate supply chain risk.

Finally, the main managerial implication is that our findings help to solve a very specific and important managerial problem: managing unforeseen supply-side disruptions. We have been able to pinpoint the particular practices that really lead to improved recovery of manufacturing operations performance for the buying firm; some proactive and some reactive. Hence, one key lesson learned is that all mitigation is not just reactive. Firms that have not started to develop resilience capabilities should not wait until something happens. Many valuable actions must be taken proactively, that is, before and in anticipation of the disruptive event. Thus, the old military saying "train hard, fight easy" applies here too. Moreover, supply-side resilience must be approached with respect for where the capability is located, that is, within the boundaries of the buying firm or along its wider supply chain.

Note

1. Additional material explaining the process of testing complementarities is available upon request.

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