A CONTINGENT RESOURCE-BASED PERSPECTIVE OF SUPPLY CHAIN RESILIENCE AND ROBUSTNESS

EMMA BRANDON-JONES
University of Manchester

BRIAN SQUIRE
University of Bath

CHAD W. AUTRY
University of Tennessee

KENNETH J. PETERSEN
University of Tennessee

Understanding supply chain resilience and robustness is increasingly important for supply chain managers. This is due to the growing complexity of contemporary supply chains and the subsequent increased probability of experiencing a disruption. Few studies within the risk management literature have empirically disentangled the concepts of resilience and robustness or explored their antecedents. This study utilizes a contingent resource-based view perspective to understand the relationship between specific resources (information sharing and connectivity), capabilities (visibility), and performance in terms of supply chain resilience and robustness. In addition, it utilizes supply base complexity as a moderating factor. Survey data collected from 264 UK manufacturing plants suggest that supply chain connectivity and information sharing resources lead to a supply chain visibility capability which enhances resilience and robustness. Of the four dimensions of complexity, only scale is found to have a strong moderating effect on this relationship, while geographic dispersion, differentiation, and delivery complexity do not have contingent effects. This study highlights theoretical and managerial implications for approaches to resilience and robustness.

Keywords: *risk management; supply chain resilience; supply chain robustness; resource-based view; supply management; buyer/supplier relationships; survey methods; regression analysis; factor analysis*

INTRODUCTION

Supply chain risk management remains a key managerial challenge that affects the performance of organizations (Altay & Ramirez, 2010; Hendricks & Singhal, 2005b). Despite increased attention from academia and industry, the frequency and impact of disruptions remains stubbornly high. In part, this may be ascribed to rises in events, such as natural disasters, that are outside of managerial control (Guha-Sapir, Vos, Below & Ponserre, 2012), but is also due to changes in the design of supply chains. Characteristics such as tighter coupling, increased complexities, reduced inventory levels, and ever-greater geographic dispersion have reduced costs in supply chains, but have also created greater vulnerabilities (Bode, Wagner, Petersen & Ellram, 2011).

As a result, many organizations, including Boeing, Cisco, Coca-Cola, and Proctor and Gamble (www.scrlc.com), are working with organizations across their supply chains to create resilience and robustness. We define supply chain resilience as *the ability of a supply chain to return to normal operating performance, within* *an acceptable period of time, after being disturbed* (cf. Christopher & Peck, 2004) and supply chain robustness as *the ability of the supply chain to maintain its function despite internal or external disruptions* (cf. Kitano, 2004). For example, Toyota was able to resume production at 29 plants just 3–4 days after the Kobe earthquake of 1995 (Fujimoto, 2011), while Li and Fung were able to continue to supply their customers in the midst of the Indonesian currency crisis when many of their competitors had to halt production (Tang, 2006b). The former is an example of a resilient supply chain and the second an example of a robust supply chain.

This study applies the contingent resource-based view (RBV; Brush & Artz, 1999) to help our understanding of *how* and *when* organizations can create supply chain resilience and robustness. The RBV argues that organizations may achieve competitive advantage through the bundling of resources to create capabilities (Barney, 1991), while the contingent RBV suggests that this is dependent on certain conditions. In this study, visibility is considered to be a key capability in reducing supply chain risk (Christopher & Lee, 2004), yet surprisingly, broad empirical evidence for its effects appear largely absent from the literature. Visibility is such an important antecedent to risk reduction, not only because its presence helps organizations proactively track products and identify potential disruptions, but also because its absence can create new risks. This is exemplified by what Christopher and Lee (2004) term the "risk spiral" and is associated with the accumulation of buffer stock and the creation of long pipelines. We examine two critical resources in the development of supply chain visibility: supply chain connectivity and information sharing, where connectivity relates to the technological infrastructure through which information is conveyed to supply chain partners (Zhu & Kraemer, 2002) and information sharing relates to the nature, speed, and quality of the information being conveyed (Cao & Zhang, 2011).

Our model is explicitly predicated on the notion of resource bundling, whereby resources which are possessed by the organization, in this case supply chain connectivity and information sharing, are integrated to create capabilities, in this case supply chain visibility. While the majority of the RBV literature examines resources and capabilities associated with creating value and/or competitive advantage, risk management is primarily a value protection activity (Paape & Speklé, 2012). Therefore, we suggest that visibility is a specific capability that allows the organization to mitigate threats in their supply chain to safeguard organizational performance.

Recent theorizing within resource management (Sirmon, Hitt & Ireland, 2007), or orchestration (Sirmon, Hitt, Ireland & Gilbert, 2011), also suggests that there are contingencies that impact the effectiveness or outcomes of the bundling process. Environmental factors such as dynamism can change the effect of capabilities on competitive outcomes (Sirmon et al., 2007). Our study is consistent with this logic and examines the contingent effects of supply base complexity on the outcomes of visibility. Because supply chains are increasingly complex (Blackhurst, Craighead, Elkins & Handfield, 2005), we argue that visibility will see maximum returns to resilience and robustness when supply bases are complex. Supply chains that are relatively localized and small may be able to rely on personal and informal communication mechanisms to manage risks. However, where supply chains grow, becoming complex and globalized, the ability to understand inventory and demand reduces some of the uncertainty associated with longer pipelines and allows organizations to quickly and accurately reroute product flows if disruptions occur.

This study offers three main contributions to the literature. First, building on research by Barratt and Oke (2007) and Wieland and Wallenburg (2013), we investigate the benefits of visibility on reducing risk (Rao & Goldsby, 2009). Blackhurst et al. (2005) demonstrate the significant impact visibility can have for disruption recovery, yet empirical survey evidence is broadly absent (Rao & Goldsby, 2009). Second, we extend the RBV analysis of supply chain visibility (Barratt & Oke, 2007), to add the contingent effects of supply base complexity, specifically answering calls within the field of supply chain risk management (Blackhurst et al., 2005). Finally, we address calls for more theory application in the field of supply chain risk management (SCRM; Manuj & Mentzer, 2008). SCRM is a nascent field (Sodhi, Son & Tang, 2012), and therefore in line with the principles of methodological fit (Edmondson & Mcmanus, 2007), has broadly focused on exploratory, atheoretical analysis of concepts. We leverage a contingent RBV to show how visibility as a capability (cf. Barratt & Oke, 2007) influences resilience and robustness and moreover how this effect is dependent on supply base complexity.

The remainder of the paper is structured as follows. First, we introduce our theoretical perspective and review the literature on the contingent RBV. We then present our literature review of supply chain resilience, robustness, and visibility before detailing our hypothesis development. Next, we describe our methodology and measures before presenting our findings. Finally, we discuss these findings in the context of empirical and theoretical contributions, managerial implications, limitations, and suggestions for future research.

THEORETICAL FRAMING

The Need for a Contingent Resource-Based View

The RBV asserts that an organization can achieve competitive advantage by creating bundles of strategic resources and/or capabilities (Barney, 1991; Hoopes, Madsen & Walker, 2003; Rumelt, 1984). Purchasing and supply chain management have been identified as having the potential to generate competitive advantage (Barney, 2012; Priem & Swink, 2012), so long as the resources or capabilities have the attributes of being valuable, rare, inimitable, and nonsubstitutable (Barney, 1991). Although antagonists of the RBV criticize the lack of clarity between terms such as resources and capabilities, these are increasingly differentiated within the extant literature. Resources have been categorized as physical capital, human capital, and organizational capital (Barney, 1991) and have been extended to include financial capital, technological capital, and reputational capital (Grant, 1991). They may be tangible, such as infrastructure, or intangible, such as information or knowledge sharing (Größler & Grübner, 2006). Resources are "something a firm possesses or has access to, not what a firm is able to do" (Größler & Grübner, 2006, p. 460). As such, they may not provide value on their own but instead need to be processed or utilized in bundles in order to drive performance (Newbert, 2007). Bundling refers to the integration of resources to allow capability development (Sirmon, Gove & Hitt, 2008). This bundling process is necessary in order "to exploit opportunities and/or mitigate threats" (p. 922) in a specific context if organizations are to achieve or maintain competitive advantage (Sirmon et al., 2008).

Organizational capabilities are defined as a higher-order construct which relies on the bundling of resources (Wu, Yeniyurt, Kim & Cavusgil, 2006). When resources are combined and utilized together, they create capabilities (Grant, 1991). The bundling of resources is necessary to create unique capabilities which create value (Sirmon et al., 2007, 2008) and are potentially superior to those of competitors (Lu, Zhou, Bruton, & Li 2010). These capabilities must be those identified as necessary for the organization (Hitt, 2011), therefore they are dependent on the environmental conditions in which the organization exists. The existence and utilization of capabilities may help to explain how organizations achieve or sustain competitive advantage (Wu et al., 2006). Competitive advantage created by capabilities will be more deeply embedded within the organization's management and processes and therefore more likely to be sustainable than competitive advantage created purely by resources (Brush & Artz, 1999).

Resources and capabilities have been explored together in a limited number of studies. For example, Ravichandran and Lertwongsatien (2005) examine the effect that information systems resources and capabilities have on organizational performance. They find that information systems capabilities are necessary in order for an organization to utilize information technology effectively and that information systems capabilities rely on technological, human, and relational resources. Hitt, Bierman, Shimizu, and Kochhar (2001) identify that the capability to leverage human capital resources may lead to improved performance; however, the resource of human capital alone and its interplay with the previously outlined capability do not enhance performance as they may increase costs. Zhu and Kraemer (2002) find some evidence supporting the fact that the interplay between IT infrastructure (as a resource) and e-commerce capability may lead to increased performance. They suggest that capabilities need to be developed in order to exploit existing resources.

Despite the prevalence of the RBV within the extant literature, it has been argued that the theory suffers from "context insensitivity" (Ling-yee, 2007, p. 360). This suggests that it is unable to identify the conditions in which resources or capabilities may be most valuable (Ling-yee, 2007). Contingency theory addresses this notion of contingent conditions and argues that internal and external conditions will influence how to manage an organization or supply chain (Grötsch, Blome, and Schleper 2013) and subsequently may affect the resources or capabilities needed to drive performance under diverse conditions. Contingency theory suggests that organizations must adapt depending on the environmental conditions in which they exist (Donaldson, 2001). A contingent RBV has been suggested by scholars as it helps to address the somewhat static nature of the RBV. The development of this is useful to evaluate the extent to which different organizational resources or capabilities may provide value (Aragón-Correa & Sharma, 2003), to further enhance the usefulness of the theory (Brush & Artz, 1999), and to identify conditions which affect the utility of different resources or capabilities. Contingencies have been identified as critical in the realization of competitive advantage created by resources and capabilities, especially in relation to selection and deployment (Sirmon & Hitt, 2009). Contingency factors such as national context and culture, firm size, strategic context, and other organizational variables have been considered within the operations and supply chain management literature (Sousa & Voss, 2008). Contingency research is highlighted as necessary for the development of operations and supply chain management (Sousa & Voss, 2008); however to date, contingent perspectives on the RBV are underdeveloped in the literature.

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

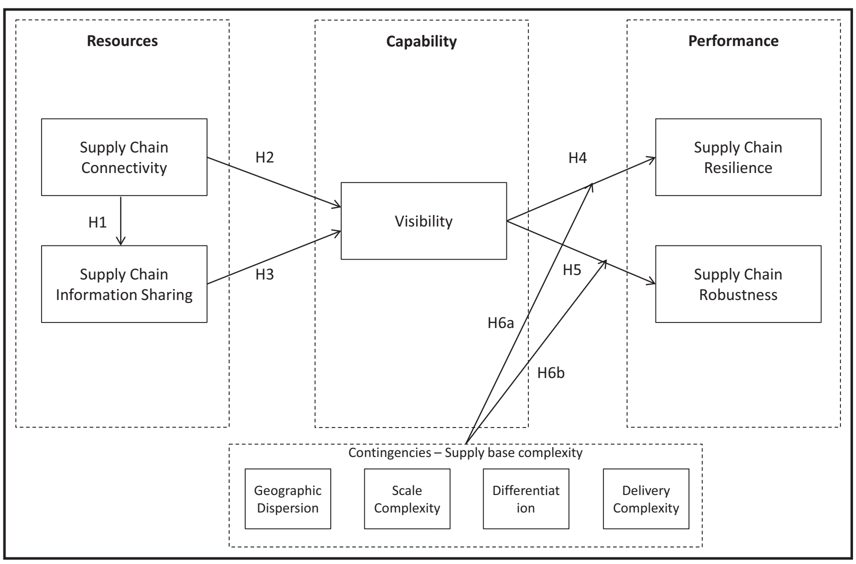
Supply Chain Resilience and Robustness

From the RBV perspective, supply chain resilience and robustness can be understood as performance outcomes (see Figure 1). As supply chain disruptions may have severe and long-term economic impacts (Hendricks & Singhal, 2005a,b), resilience and robustness may be created to mitigate threats to organizational performance. A core concern of this paper is to theoretically and empirically distinguish supply chain resilience from supply chain robustness. While prior research has, on occasion, conflated the two terms, used them interchangeably (Christopher & Peck, 2004), and/or switched the causal logic, their conceptual meaning is actually distinct. Supply chain resilience is defined as *the ability of a system to return to its original state, within an acceptable period of time, after being disturbed*. This definition is consistent with previous research such as that of Sheffi (2005) and Christopher and Peck (2004). Resilience implies that the disruption has a negative impact on the system but that it is able to recover to its original state.

Increased resilience within the supply chain is deemed to be positive (Blackhurst, Dunn & Craighead, 2011), and extant research details strategies to build resiliency (e.g., Manuj & Mentzer, 2008). Ponomarov and Holcomb (2009, p131) define supply chain resilience as "the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function." Although this definition has some similarities to that used in this study, we argue that resilience is an output measure which is dependent on capabilities such as visibility. In addition, we argue that "maintaining continuity" relates more to robustness than resilience. However, various definitions exist in the literature due to its nascent stage (Blackhurst et al., 2011), and the concept of resilience requires further empirical research (Bhamra, Dani & Burnard, 2011).

Supply chain robustness is defined as *the ability of the supply chain to maintain its function despite internal or external disruptions* (cf. Kitano, 2004). Definitions of robustness focus on the ability to continue with operations (Stonebraker, Goldhar & Nassos, 2009) while resisting the impact of supply chain disruptions. It has been argued that supply chain robustness has yet to be clearly defined in the supply chain risk literature and remains misunderstood (Vlajic, van Lokven, Haijema & van der Vorst, 2012). In addition, further work, for example developing scales, is required (Natarajarathinam, Capar & Narayanan, 2009). Robustness is frequently misunderstood to be a static concept, implying that a system and its operations remain unchanged in the face of perturbations. In fact, robust systems often require change at the structural or component level to maintain functionality (Kitano, 2004). For example, many electronic firms qualify a second supplier and assign a small

FIGURE 1
Hypothesized Relationships



proportion (circa 5% per annum) of spend. Qualifying and maintaining a second supplier might increase direct and indirect costs but provides responsive switching in the event of a disruption. This "fail safe mechanism" means that components of the system can adapt in response to specific perturbations while maintaining overall operating performance.

Supply Chain Visibility

Prior research has conceptualized supply chain visibility as a capability (Barratt & Oke, 2007; Jüttner & Maklan, 2011) which may reduce the negative impacts of a supply chain disruption (Christopher & Lee, 2004). Within the RBV, capabilities are understood to influence performance (see Figure 1) or lead to sustained competitive advantage (Newbert, 2007; Wu et al., 2006). The concept of supply chain visibility has been largely under-refined within the extant literature and a consistent definition is still absent (Francis, 2008). At times, there has been a lack of distinction between information sharing and visibility (Barratt & Oke, 2007). While information sharing is predominantly concerned with the quality and relevance of information provided (Cao & Zhang, 2011), visibility is concerned with the information flow in terms of inventory and demand levels within the supply chain at a given time (Braunscheidel & Suresh, 2009) and enables supply chains to be more transparent (Christopher & Lee, 2004). Information sharing is therefore regarded as an intangible internal resource, while supply chain visibility is seen as a broader capability whereby material and information flows are captured.

In order to share information, organizations have focused on the creation of linkages across the supply chain to enhance the visibility of their supply chain operations (Mabert & Venkataramanan, 1998). The use of these external linkages may improve both visibility and supply chain performance, for example through reducing the negative effect of demand distortions (Lee, So & Tang, 2000), allowing organizations to be more agile (Christopher, 2000), creating strategic value (Wei & Wang, 2010), and improving operational efficiency and planning (Caridi, Crippa, Perego, Sianesi & Tumino, 2010). Barratt and Oke (2007) suggest that the relationship between information sharing and performance is mediated by visibility and that operational performance can be enhanced through increased visibility. In addition, supply chain visibility may help to mitigate supply chain risk through improved confidence, reduced interventions, and improved decision-making (Christopher & Lee, 2004) as well as enhancing resilience (Jüttner & Maklan, 2011). However, the relationship between supply chain visibility, and both supply chain resilience and robustness, has not yet been empirically explored through survey data.

The Impact of Connectivity on Information Sharing

According to RBV logic, resources may need to be combined and utilized together in order to create capabilities (Grant, 1991). Both supply chain connectivity and information sharing can be positioned as resources (see Figure 1), which may lead to a visibility capability through the bundling of these resources (Sirmon et al., 2007). Bundling resources obtained from suppliers has been identified as being complex (Hitt, 2011); although the resources of connectivity and information sharing may be defined as boundary spanning, they still reside within the control of the focal organization. Information sharing can be categorized as organizational capital, a resource which focuses on the flow of information (Premkumar & King, 1994). Its utility is dependent on its quality (Zhou & Benton, 2007). However, the quality, accessibility, accuracy, and relevance of the information (Cao & Zhang, 2011) are reliant on effective delivery. Therefore, the intangible nature of information sharing can be seen to be dependent on tangible IT infrastructure or support technology, otherwise referred to as supply chain connectivity (Fawcett, Osterhaus, Magnan, Brau & McCarter, 2007). Connectivity is an example of a technological resource, which enables the effective sharing of the information (Barratt & Oke, 2007) and compatible systems reduce risk (Zsidisin, 2003). In addition, supply chain connectivity facilitates more successful decision-making and improved coordination (Fawcett, Wallin, Allred & Magnan, 2009). Therefore,

H1: Supply chain connectivity has a positive impact on information sharing.

The Impacts of Connectivity and Information Sharing on Visibility

According to the RBV, strategic resources and/or capabilities may lead to competitive advantage (Barney, 1991) and resources may be tangible or intangible (Größler & Grübner, 2006). The bundling of resources may lead to capability development (Grant, 1991). Supply chain connectivity relates to the tangible resources necessary to share information through a supply chain such as information systems. Connectivity might also be referred to as an organization's IT infrastructure which is perceived as an important business resource (Zhu & Kraemer, 2002). It may be defined as a resource and seen to facilitate the development of capabilities within the supply chain (Wu et al., 2006). Connectivity refers to an organization's ability to gather and share information (Fawcett, Wallin, Allred, Fawcett & Magnan, 2011) through the use of information and communication technologies (ICTs). However, while technology may provide the platform for supply chain visibility, information sharing is by no means guaranteed (Fawcett et al., 2011). The utility of supply chain connectivity is dependent on the nature and quality of information shared. The existence of supply chain connectivity allows organizations within a supply chain to share information (Fawcett et al., 2011) and is therefore a prerequisite for the successful development of a supply chain visibility capability. Therefore,

H2: Supply chain connectivity has a positive impact on supply chain visibility.

Information sharing relates to intangible resources concerning the nature of information shared. Information itself may be seen as a resource (Barney, 1991) and should be timely, full, correct, pertinent, and confidential (Cao & Zhang, 2011). The sharing of appropriate and timely information between supply chain actors may lead to improved visibility (Christopher & Lee, 2004), especially strategies which relate to information sharing regarding inventory and demand levels across the supply chain (Tang, 2006a,b). When information sharing is successful, it may lead to visibility and more open exchange between supply chain actors.

While supply chain connectivity provides the tangible resource which allows the real-time seamless interaction of actors across the supply chain through the use of ICTs (Fawcett et al., 2007), information sharing provides the intangible resources regarding the nature of information and appropriate and timely sharing. The bundling of these resources may lead to the development of a capability (Sirmon et al., 2007) that of supply chain visibility (Christopher & Lee, 2004; see Figure 1). Therefore,

H3: Information sharing has a positive impact on supply chain visibility.

The Impact of Visibility on Supply Chain Resilience and Robustness

Developments in the RBV suggest that holding valuable and rare resources is a necessary but not sufficient condition to achieve competitive advantage (Hitt, 2011). Additionally, resources must be bundled into capabilities required by the organization and these capabilities must be effectively leveraged to create or protect value (Sirmon et al., 2008). Our study is particularly interested in the notion of value protection where the development of supply chain resilience and robustness has clear implications for operating performance (Hendricks & Singhal, 2005a,b) and shareholder wealth (Hendricks & Singhal, 2005a,b). We suggest that an improved supply chain visibility capability may reduce both the probability and impact of a supply chain disruption (Christopher & Lee, 2004) and therefore lead to enhanced robustness and/or resilience (Jüttner & Maklan, 2011).

Kleindorfer and Saad (2005) suggest that it is a requirement of the risk management process of supply chains to have system-wide visibility of vulnerabilities. If managers are able to identify possible threats or sources of disruption, they can start to develop business continuity plans and scenarios that should help speed up recovery in the event of a disruption. For example, joint continuity planning ensured that a buying organization was prioritized in the event of a big supplier closing down capacity (Jüttner & Maklan, 2011), therefore increasing the speed of recovery. Tang (2006a,b) suggests that increased visibility would enable parties in the supply chain to generate a common demand forecast that, if combined with a proportional restoration rule, could aid the efficient return to normal inventory levels in the event of a disruption. In this case, visibility is reducing the resource intensity required for recovery. Thus,

H4: Supply chain visibility has a positive impact on supply chain resilience.

A supply chain visibility capability also promotes robustness. System-wide visibility allows organizations to identify a broad range of bottlenecks and other potential risks and therefore take mitigating action before a disruption occurs. For example, visibility of the system allowed a retailer to divert inventory to a different port in advance of the strike at the Port of Los Angeles (Craighead, Blackhurst, Rungtusanatham & Handfield, 2007). More recently, we have also seen moves to develop cross-industry collaborations to identify broad systems risks that can only be identified when organizations share information and create visibility of inventory data. For example, Toyota, Jaguar Land Rover, and Aston Martin are collaborating to create visibility of their supply chains: "We were never going to do this alone…But collaborations really benefit the automotive industry as a whole" (David Wyer, Senior Purchasing Manager for Aston Martin cited in Jones, 2013). Visibility allows organizations to identify and prepare for a broad range and amplitude of risks.

Similarly, visibility of demand information may also help to reduce exposure to specific risks, such as forecast risk or the risk of distorted demand signals (Chopra & Sodhi, 2004; Lee, 2010). For example, visibility of the demand signal is critical to the production scheduling and inventory control of Zara. By sharing information between each store and the headquarters on a daily basis, Zara can dynamically adjust the production schedule and therefore substantially reduce the probability of stockouts or excess inventory (Ferdows, Lewis & Machuca, 2004). This visibility capability is of great value to the organization. Thus,

H5: Supply chain visibility has a positive impact on supply chain robustness.

The Moderating Role of Supply Base Complexity

In a recent review of the RBV, Kraaijenbrink, Spender and Groen (2010, p. 365) argue that "the moment we try to explain or predict the firm's actual performance…the RBV turns out to be incomplete because it ignores the material contingencies of the firm's situation." Our study responds to this challenge to examine the contingent effect of supply base complexity on the relationships between supply chain visibility, resilience, and robustness (see Figure 1). Although enhanced supply chain visibility may lead to a reduced likelihood of experiencing, or suffering deleterious consequences as a result of, a supply chain disruption, the contingent conditions under which the additional cost of improving visibility is worthwhile are less clear (Blackhurst et al., 2005). Given that there is a broad portfolio of supply chain risk options available to managers, including insurance products, risk sharing contracts, developing flexibility, and so on, it is critical for managers to understand the conditions under which improving visibility will provide a strong return on investment. Within this study, we examine the effects of supply base complexity on the relationship between supply chain visibility and supply chain resilience and robustness.

Supply base complexity relates to the number of suppliers (scale complexity), delivery reliability of suppliers (delivery complexity), differentiation between suppliers, and geographic dispersion (Caridi et al., 2010; Choi & Krause, 2006; Vachon & Klassen, 2002). Complexity is increased as organizations utilize a higher number of suppliers as there are additional relationships to manage, alongside additional information and product flows to oversee (Bozarth, Warsing, Flynn, & Flynn 2009). Delivery with longer lead-times creates complexity through the requirement of further data (Frank, Drezner, Ryan & Simchi-Levi, 2000) and extended planning times (Simangunsong, Hendry & Stevenson, 2012). Differences between suppliers generate complexity because managers must deal with a range of cultural, practical, and technical differences (Choi & Krause, 2006). Finally, when suppliers are geographically dispersed, a number of issues arise which increase complexity: cultural and linguistic differences (Stringfellow, Teagarden & Nie, 2008); unpredictable quality (Gray, Roth & Leiblein, 2011); and variable lead-times (Holweg, Reichhart & Hong, 2011).

We argue that each dimension of complexity creates greater uncertainty and therefore an additional opportunity for visibility to benefit managers. Localized, small and undifferentiated networks are, by nature, more robust and resilient to failure. However, the uncertainties created by supply base complexity mean that supply chain visibility will have a greater effect on reducing the probability of failure and improving the speed of response in more complex supply chains. Additional insights can be gained through visibility that allows managers to become aware of vulnerabilities that were hidden through complex networks. Organizations often lack visibility past their tier 2 suppliers and this proved to be problematic during the Japanese 2011 tsunami and earthquake where lack of visibility alongside a just-in-time strategy of low inventory levels led to significant delays within the automotive industry (Bunkley, 2011). Therefore,

H6a: Supply base complexity positively moderates the relationship between visibility and supply chain resilience: the higher the complexity, the greater the beneficial effects of visibility on resilience.

H6b: Supply base complexity positively moderates the relationship between visibility and supply chain robustness: the higher the complexity, the greater the beneficial effects of visibility on robustness.

Figure 1 illustrates our theoretical model. It summarizes the relationships between the two resources (connectivity and information sharing), the capability (visibility), the performance measures (resilience and robustness), and the contingencies (complexity).

METHODOLOGY

Sample and Data Collection

The unit of analysis employed in this study was at the level of a manufacturing plant and its constituent upstream suppliers. Prior research has indicated that this unit of analysis provides a detailed understanding of how supply chain design affects performance (Bozarth et al., 2009; c.f. Naor, Linderman & Schroeder, 2010). The target sample was composed of managers included in the Chartered Institute of Purchasing and Supply (CIPS) database. We selected 1,200 potential respondents by their job function (supply manager or equivalent), and industry codes reflecting mining, construction, or manufacturing (NAICS codes 11000, 15000, 16000, 17000, 19000, 20000, 21000, and 23000–39000). We selected supply managers as key respondents because we deemed them to be the most knowledgeable about manufacturing plant supply chains and our related subjects of interest: supply chain strategy, practices, resilience, and robustness, and the performance of UK manufacturing plants.

The hypotheses were tested with data collected from a postal survey, which have previously been shown to have higher response rates than internet-based surveys (Shannon & Bradshaw, 2002). The survey construction and application processes followed Dillman's total design method (2000). First, we phoned each contact to discuss the purpose of the survey and to invite participation. Next, we sent a copy of the cover letter and survey to each respondent three times over a number of months. We incentivized participation through the offer of a charitable donation to four national and international charities. Each respondent could select one of these charities. In addition, we offered respondents the opportunity to receive an executive summary reporting our findings and including implications for practice. A total of 264 usable responses were received, representing an effective response rate of 22%. We provide a profile of respondents in Table 1.

As is the case with all survey research, the potential for biases exists in our study. We tested nonresponse bias through a comparison of early respondents (questionnaires received in the first 2 weeks), late respondents (questionnaires received in the third week or later), and nonrespondents (a subsample of 25 nonrespondents was selected at random from the initial contact list; Armstrong & Overton, 1977; Lambert & Harrington, 1990). There was no significant difference between early and late respondents on any of the variables used. Similarly, there was no significant difference between respondents and nonrespondents in terms of plant size or industry code.

Additionally, because we measured both the dependent and independent variables in our study with the same instrument, it was necessary to assess common method variance. First, Harman's one-factor test was employed (Podsakoff & Organ, 1986), whereby all scale items were simultaneously entered into a principal component factor analysis with varimax rotation. The results yielded eight factors explaining 70.46% of the variance, with the first factor only accounting for 13.51% of the total variance. These results suggest that no single factor structure emerged, nor did one factor account for the majority of the variance. Second, we ran a modified version of this test as suggested by Malhotra, Kim, and Patil (2006). The fit indices indicated that a hypothesized model consisting of a single factor had very poor fit ($\chi^2(364) = 2010.105$; comparative fit index [CFI] = .64; incremental fit index [IFI] = .64; GFI = .75 root mean square error of approximation [RMSEA] = .13), and we therefore conclude that common methods bias is not problematic for our dataset.

TABLE 1

Descriptive Statistics of Sample Frame

Title	Number	Percentage
Annual sales revenue		
Under £10 Million	38	14.5
£11–25 Million	48	18.4
£26–50 Million	40	15.2
£51–75 Million	23	8.6
£76–100 Million	13	4.7
£101–250 Million	27	10.2
£251–500 Million	23	8.6
Over £501 Million	52	19.9
Total	264	100
Number of employees		
0–50	31	11.7
51–100	45	17.2
101–200	50	18.8
201–500	62	23.4
501–1000	27	10.2
1001+	49	18.7
Total	264	100
Industry sector		
Oil and gas	14	5.3
Food and beverage	17	6.4
Textiles & apparel	4	1.5
Wood products	1	.4
Paper products	7	2.7
Chemical products	23	8.7
Rubber & plastic products	8	3
Basic & fabricated products	26	9.8
Machinery	48	18.2
Electrical and optical equipment	51	19.3
Automotive & transport	37	14
Furniture	26	9.8
Total	264	100

Measures

Whenever possible, this study adopted established scales from the literature (Malhotra & Grover, 1998). This was feasible for measures of supply chain connectivity, information sharing, supply chain visibility, and geographic dispersion. We could not identify suitable measures of supply base complexity, robustness, and resilience. Scale development procedures for these constructs followed Churchill's (1979) scale development methodology including a comprehensive literature review, followed by pretesting with managers and academics in the field of supply chain management. We made minor modifications to the wording of items based on the feedback from pretests in order to improve scale performance. With the exception of a control variable examining environmental dynamism (see below), all scales were designed in 5-point Likert format anchored as 1 = strongly disagree and 5 = strongly agree.

EXOGENOUS VARIABLES

Supply Chain Connectivity

We measured connectivity using a scale developed by Fawcett et al. (2011). The three items ($\alpha = .80$) examine the extent to which information systems are integrated within the firm and supply chain to satisfy communication needs.

Information Sharing

We measured information sharing using a scale developed by Cao and Zhang (2011). The five items ($\alpha = .77$) assess the extent of relevant, timely, accurate, and complete information sharing occurring between the manufacturer and its suppliers.

ENDOGENOUS VARIABLES

Supply Chain Visibility

We measure visibility using a scale developed by Braunscheidel and Suresh (2009). The two items ($r = .65$) examine the extent to which inventory and demand levels are visible throughout the supply chain.

Supply Base Complexity

Four measures of complexity were developed from Bozarth et al. (2009), Choi and Krause (2006), and Caridi et al. (2010): (1) scale, (2) differentiation, (3) delivery, and (4) geographic dispersion. Supply chains are more complex if they involve more players, the players are dissimilar, lead-times are long and/or unreliable, and the players are more geographically dispersed. As predicted, factor analysis revealed that the six items reflecting the first three dimensions formed distinct factors, termed scale ($r = .67$), similarity ($r = .56$), and reliability ($r = .52$). The final dimension of complexity, geographic dispersion, was measured with a scale developed by Stock, Greis, and Kasarda (2000). Respondents were asked to specify the percentage of their plant's suppliers located in the following regions: Europe, Asia, North America, and other. Dispersion was then calculated using the following formula:

$$\mathrm{DISP} = 1 - \frac{(|\mathrm{Europe}\% - 25| + |\mathrm{Asia}\% - 25| + |\mathrm{N.\ America}\% - 25| + |\mathrm{Other}\% - 25|)}{150} \quad (1)$$

Values ranged from 0 (where all suppliers are concentrated in a single region) to 1 (where all suppliers are spread equally across all four regions).

Supply Chain Resilience. As discussed in the literature review, resilience references the ability of a supply chain to bounce back from a disruption. The four items ($\alpha = .87$) were designed to examine restoration of material flow and operating performance, recovery of the supply chain, and the speed with which disruptions would be dealt with.

Supply Chain Robustness. Robustness refers to the ability of a supply chain to withstand disruption and continue operating. The four items ($\alpha = .91$) examine whether normal operations would continue, the firm would be able to meet consumer demand, performance would not deviate from targets, and the supply chain could carry out regular functions.

Statistical Controls. We included two statistical controls that appeared to be germane to the study focus, in order to avoid model misspecification. Plant size, measured by the total number of plant employees, was included as Wagner and Neshat (2011) recently found that larger firms are more vulnerable to disruption. We also included a control for environmental (industry) dynamism in order to level out the effects of disruption across industry segments such that they became comparable. The environmental dynamism control variable took the form of a five-item, five-point Likert scale anchored as 1 = slow and 5 = rapid, with items reflecting industry rates of change for product/service introduction, operating processes, customer tastes/preferences, and research and development.

ANALYSES AND RESULTS

Measure Assessment

We conducted a confirmatory factor analysis (CFA) using AMOS 19.0 (see the results displayed in Table 2), in order to estimate the measurement properties of the multi-item constructs (i.e., all of those included in the study with the exception of the geographic dispersion measure, which was calculated). All factor loadings were in excess of the commonly accepted .40 standard (Anderson & Gerbing 1988), and the low normalized residuals and modification indices observed (all <3.5) suggested no need to delete items to improve model fit. The measurement model revealed a good fit of the model to the data. We observed a chi-square value: $\chi^2(367) = 654.18$; Tucker–Lewis Index (TLI) = .91; IFI = .92; CFI = .92; and RMSEA = .06, each supporting strong model fit.

A series of procedures were next used to assess convergent and discriminant validity for the scales. In support of convergent validity, we observed that all

TABLE 2

Confirmatory Factor Analysis

Construct[a]	Loading	*t*-Value
Supply chain connectivity (α = .80; CR = .84; AVE = .72)		
SCC1 Current information systems satisfy supply chain communication requirements	.790	—
SCC2 Information applications are highly integrated within the firm and supply chain	.752	10.92
SCC3 Adequate information systems linkages exist with suppliers and customers	.751	11.27
Information sharing (α = .77; CR = .79; AVE = .57)		
INS1 Our firm exchanges relevant information with suppliers	.821	—
INS2 Our firm exchanges timely information with suppliers	.857	3.89
INS3 Our firm exchanges accurate information with suppliers	.744	3.95
INS4 Our firm exchanges complete information with suppliers	.661	4.00
INS5 Our firm exchanges confidential information with suppliers	.559	3.99
Supply chain visibility (α = .79; CR = .81; AVE = .82)		
VIS1 Inventory levels are visible throughout the supply chain	.895	—
VIS2 Demand levels are visible throughout the supply chain	.731	9.33
Supply chain resilience (α = .86; CR = .87; AVE = .72)		
RES1 Material flow would be quickly restored	.892	—
RES2 It would not take long to recover normal operating performance	.779	11.86
RES3 The supply chain would easily recover to its original state	.790	11.71
RES4 Disruptions would be dealt with quickly	.706	13.06
Supply chain robustness (α = .90; CR = .91; AVE = .78)		
ROB1 Operations would be able to continue	.826	—
ROB2 We would still be able to meet customer demand	.861	16.04
ROB3 Performance would not deviate significantly from targets	.814	17.49
ROB4 The supply chain would still be able to carry out its regular functions	.857	16.39
Environmental dynamism (α = .83; CR = .86; AVE = .60)		
DYN1 Rate at which products and services become outdated	.672	—
DYN2 Rate of introduction of new products and services	.836	10.82
DYN3 Rate of introduction of new operating processes	.661	9.17
DYN4 Rate of change in tastes and preferences of customers in the industry	.671	9.26
DYN5 Rate of research and development (R&D) in the industry	.688	9.44
Scale complexity (α = .79; CR = .80; AVE = .83)		
CXSC1 This supply chain is very complex	.685	—
CXSC2 This supply chain involves a lot of players	.582	2.84
Differentiation (α = .73; CR = .73; AVE = .79)		
DIF1 Suppliers in this supply chain are the same size	.455	—
DIF2 Suppliers in this supply chain have the same level of technical capability	.458	1.32
Delivery complexity (α = .68; CR = .70; AVE = .76)		
CXDL1 We can depend on on-time delivery from suppliers in this supply chain	.726	—
CXDL2 We can depend on short lead-times from suppliers in this supply chain	.715	3.19

[a]All constructs were scaled as 1 = strongly disagree and 7 = strongly agree, with the exception of environmental dynamism, which was scaled as 1 = slow and 5 = rapid. The first item in each scale was fixed to a loading of 1.0 in the initial run to set the scale of the construct.

Observed CFA fit statistics were: $\chi^2(367) = 654.18$; TLI = .91; incremental fit index = .92; comparative fit index = .92; root mean square error of approximation = .06.

factor loadings were significant ($t > 2.0$) with the exception of the second differentiation item. Given this exception, we next assessed average variance extracted for all constructs; in each case, the AVE value was in excess of .50, supporting convergent validity. Discriminant validity was next assessed, via both confidence interval evaluation and AVE comparisons. Confidence intervals for construct intercorrelations were between zero and one, and all squared intercorrelations were less than the AVE estimates for either construct in a pairing, supporting discriminant validity. Table 3 displays the descriptive statistics and bivariate intercorrelations for the constructs of interest to the study.

Hypothesis Testing and Results

The hypothesized relationships were tested using multiple regression analysis, with hierarchical moderation tests applied as necessary. All variables were mean-centered to reduce the risk of multicollinearity of the interaction terms (Aiken & West, 1991). We tested for multicollinearity by calculating the variance inflation factors (VIF) for each regression coefficient. VIF values ranged from 1.002 to 1.356, significantly below the recommended threshold of 10 (Hair, Black, Babin, Anderson & Tatham, 2006). Tables 4–6 provide the results of the regression analyses.

Table 4 examines the hypothesized linkages between resources and visibility as specified in H1–H3. Addressing H1 first, we observe support (Table 4) for the prediction that supply chain connectivity is positively associated with supply chain information sharing (β = .482; $p < .001$), consistent with the findings of Barratt and Oke (2007). The control variables, environmental dynamism and firm size, do not have a significant effect in this model. We interpret these observations as evidence that rapid change speed in the manufacturing industry is not meaningfully impeding information sharing via connectivity and that firm size plays little role in the connectivity–information sharing relationship.

Next addressing H2 and H3, we find support (Table 4) for both supply chain connectivity (β = .298; $p < .001$) and information sharing (β = .297; $p < .001$), as predictors of visibility, and observe that, together with the control variables, they explain a significant portion of the variance in visibility ($R^2 = .320$). Barratt and Oke (2007) did not assess a direct connectivity–visibility relationship, but rather, only linked connectivity to visibility through information sharing. Our observation of the direct relationship implies that firms may be gaining visibility simply by virtue of establishing technological connections in the supply chain, regardless of the information content supplied through them. We also note that for our sample, the environmental dynamism control has a significant positive impact on supply chain visibility while plant size has no effect.

H4 and H5 were tested using hierarchical multiple moderated regression. Step 1 of Table 5 shows that only one of the control variables, environmental dynamism, has a significant effect on supply chain resilience (β = .241; $p < .001$). Step 2 includes the direct effects of supply chain visibility as well as the direct effects of the moderator variables. In support of H4, Table 5 indicates that visibility has a significant and positive effect on supply chain resilience (β = .169; $p < .01$), supporting previous qualitative evidence of this relationship (Jüttner & Maklan, 2011). The model also indicates that differentiation (β = −.131; $p < .05$) and delivery complexity (β = .222; $p < .001$) have significant direct effects with resilience. The results suggest that more differentiated supply bases that have more reliable suppliers with shorter lead-times are more resilient to disruptions. While the result for delivery complexity is to be expected, the negative effect of differentiation is surprising (Choi & Krause, 2006) and might indicate that there is a portfolio effect of engaging a broad range of suppliers in terms of size and technical capability.

Step 3 adds the interaction effects to our model. In partial support of H6a, the full model suggests that only scale complexity has a significant interaction effect, where the impact of visibility on resilience is stronger for higher levels of scale complexity (β = .266; $p < .001$). On the other hand, the moderat-

TABLE 3

Descriptive Statistics and Intercorrelations of Constructs

Construct	Mean	SD	1	2	3	4	5	6	7	8	9
1 SC connectivity	2.93	.90	1.00								
2 Info. sharing	3.70	.67	*.502*	1.00							
3 SC visibility	3.05	1.02	*.478*	*.473*	1.00						
4 SC resilience	3.20	.82	*.300*	*.251*	*.261*	1.00					
5 SC robustness	2.96	.83	*.179*	*.129*	*.225*	*.586*	1.00				
6 Env. dynamism	2.66	.76	*.204*	*.182*	*.257*	*.284*	*.216*	1.00			
7 Plant size (log)	n/a	n/a	.113	.073	.056	−.003	−.021	−.054	1.00		
8 Scale complexity	3.63	.91	.037	−.062	.046	*−.139*	.006	−.017	*.255*	1.00	
9 Differentiation	1.81	.78	−.116	−.009	.066	.082	−.153	.069	−.118	−.117	1.00
10 Delivery complexity	2.96	.87	*.248*	*.309*	*.232*	*.293*	*.159*	.078	.034	*−.171*	−.054

Italicized correlation coefficients are significant at $p < .05$.

TABLE 4

Regression Results for Visibility and Supply Chain Information Sharing

Variables	DV = SC Information Sharing		DV = SC Visibility	
	B	*t*-Value	*B*	*t*-Value
Controls				
Environmental dynamism	.085	1.551	.143*	4.366
Plant size	.023	.429	.009	1.178
Main effects				
Supply chain connectivity	.482**	8.777	.298**	4.969
Information sharing			.297**	4.986
Model summary				
R^2	.259		.320	
Adj R^2	.251		.310	
Model F	30.346		30.503	

Significance at $*p < .01$, $**p < .001$; coefficients are standardized.

ing effects for the other dimensions of complexity (geographic dispersion, differentiation, and delivery) have no significant effect.

We approached the relationship between visibility and supply chain robustness similarly in H5. Step 1 again finds that environmental dynamism is a significant predictor of supply chain robustness (β = .216; $p < .001$). Step 2 indicates that supply chain visibility has a significant positive effect on robustness (β = .168; $p < .01$), thus supporting H5. We also note the significant negative effect of differentiation (β = −.187; $p < .001$). Step 3 adds the interaction terms and shows that only scale complexity has a significant interaction effect, where the impact of visibility on robustness is stronger for higher levels of scale complexity (β = .192; $p < .01$). None of the other dimensions of complexity have an interaction effect, providing only partial support for H6b.

To further analyze the significant interaction effects, the relationships were plotted using values of one standard deviation above the mean to represent high levels of "scale complexity" and one standard deviation below the mean to represent low levels of "scale complexity" (Cohen & Cohen, 1983). We hypothesized that visibility may have a more significant positive effect on resilience and robustness when complexity is high. Figures 2a and b confirm our hypothesis and show that visibility has little effect when scale complexity is low but a positive effect when scale complexity is high. Furthermore, we tested the simple slopes of high scale complexity (one standard deviation above the mean) and low scale complexity (one standard deviation below the mean; Lam, Huang & Snape, 2007). In support of H6a, we found that visibility was more positively related to resilience when scale complexity was high (β = .346; $p < .001$), than when scale complexity was low (β = −.102, n.s.). Similarly, in support of H6b, we found that visibility was more positively related to robustness when scale complexity was high (β = .293; $p < .01$), than when scale complexity was low (β = −.033, n.s.).

Finally, given the logical structure of our theorized model, it was desirable to undertake an exploratory assessment of whether supply chain visibility serves as a full or partial mediator linking supply chain connectivity and/or supply chain information sharing to the resilience and robustness performance outcomes. We did so following the prescriptions of Zhao, Lynch, and Chen (2010), who provided an updated procedure versus the traditionally employed Baron and Kenny (1986) mediation testing procedure. This assessment led to evidence of partial (indirect plus direct) mediation in each of the four cases under examination. Specifically, the direct path coefficients for each of the four pairings of antecedent and outcome variables were significant and same sign as the AB terms for the indirect paths, with all 95% confidence intervals excluding zero. Although scarce theoretical rationale for this assessment has been developed as yet in the literature, these exploratory tests motivate future studies that would parse out the differential effects of resources versus the visibility capability when predicting resilience and robustness.

DISCUSSION

Empirical and Theoretical Implications

The RBV is concerned with the bundling of strategic resources and/or capabilities (Barney, 1991) to create and protect competitive advantage. From this perspective, information sharing and connectivity may be

TABLE 5

Hierarchical Moderated Regression Results for Supply Chain Resilience

	Control Model		Main Effects Model		Full Model	
Variables	*B*	*t*-Value	*B*	*t*-Value	*B*	*t*-Value
Controls						
Environmental dynamism	.285***	4.794	.241***	4.146	.259***	4.569
Plant size	.013	.212	.039	.665	.067	.255
Main effects						
Visibility			.169**	2.829	.153**	2.615
Geographic dispersion			−.071	−1.177	−.046	−.787
Scale complexity			−.111	−1.841	−.130*	−2.205
Differentiation			−.131*	−2.321	−.137*	−2.205
Delivery complexity			.222***	3.818	.222***	3.838
Interaction effects						
Visibility × geographic dispersion					−.087	−1.502
Visibility × scale complexity					.266***	4.460
Visibility × differentiation					.006	.112
Visibility × delivery complexity					.091	1.586
Model summary						
R^2	.081		.207		.267	
Adj R^2	.074		.185		.235	
Model F	11.492***		9.539***		8.331***	
ΔR^2			.126		.060**	
ΔF			8.130***		5.138***	

Significance at *$p < .05$, **$p < .01$, ***$p < .001$; coefficients are standardized.

seen as complementary resources which may be bundled in order to lead to a visibility capability (cf. Sirmon et al., 2007). Arguably, the tangible resource of supply chain connectivity might be more valuable in conjunction with the intangible resource of information sharing. Although we find that both connectivity and information sharing lead to visibility, connectivity may also lead directly to information sharing (Barratt & Oke, 2007), suggesting an interplay between these resources. When combined or bundled, resources may lead to capabilities (Grant, 1991; Sirmon et al., 2007), which are often more greatly embedded within an organization and provide superior value (Brush & Artz, 1999). Consequently, capabilities may be leveraged to exploit opportunities or mitigate threats (Sirmon et al., 2008), but their outcomes are contingent upon the specific context. We examine the value protection effects of supply chain visibility on supply chain resilience and robustness under the contingent conditions of varying levels of supply base complexity.

Our study makes a number of important contributions to the extant literature. First, this paper demonstrates that resilience and robustness are discrete concepts (Christopher & Peck, 2004), as shown in the factor analysis where they emerge as distinct constructs. This is one of the first studies to empirically disentangle these concepts which are often conflated in the extant literature. Resilience relates to the concept of an organization being able to rapidly bounce back from the effects of a disruption, while robustness refers to an organization's ability to maintain functionality despite disruption.

Second, this study provides empirical evidence that supply chain visibility acts as an antecedent to both supply chain resilience and robustness (see Figure 1). This is one of the first studies utilizing survey data to test such hypothesized relationships. Resilience may be enhanced because organizations better understand demand and inventory levels and can therefore develop continuity plans which allow them to respond more rapidly to disruptions (Jüttner & Maklan, 2011). In addition, visibility can encourage more efficient knowledge sharing to reduce the resources required to respond. Robustness may be augmented by the early identification of delays or disruptions from bottlenecks to large labor strikes (Craighead et al., 2007) enabling organizations to deal with a variety of types and magnitudes of events before they cause any material disruption to the organization.

TABLE 6

Hierarchical Moderated Regression Results for Supply Chain Robustness

Variables	Control Model B	Control Model t-Value	Main Effects Model B	Main Effects Model t-Value	Full Model B	Full Model t-Value
Controls						
Environmental dynamism	.216***	3.567	.175**	2.856	.188**	3.110
Plant size	−.012	−.193	−.041	−1.653	−.017	−.278
Main effects						
Visibility			.168**	2.675	.162**	2.585
Geographic dispersion			.002	.034	.019	.308
Scale complexity			−.003	.050	−.016	−.260
Differentiation			−.187**	−3.151	−.184**	−3.071
Delivery complexity			.114†	1.868	.112	1.816
Interaction effects						
Visibility × geographic dispersion					−.039	−.635
Visibility × scale complexity					.192**	3.014
Visibility × differentiation					.060	.986
Visibility × delivery complexity					.094	1.542
Model summary						
R^2	.047		.123		.161	
Adj R^2	.040		.100		.124	
Model F	6.437		5.152***		4.393	
ΔR^2			.076		.037	
ΔF			4.467***		2.810*	

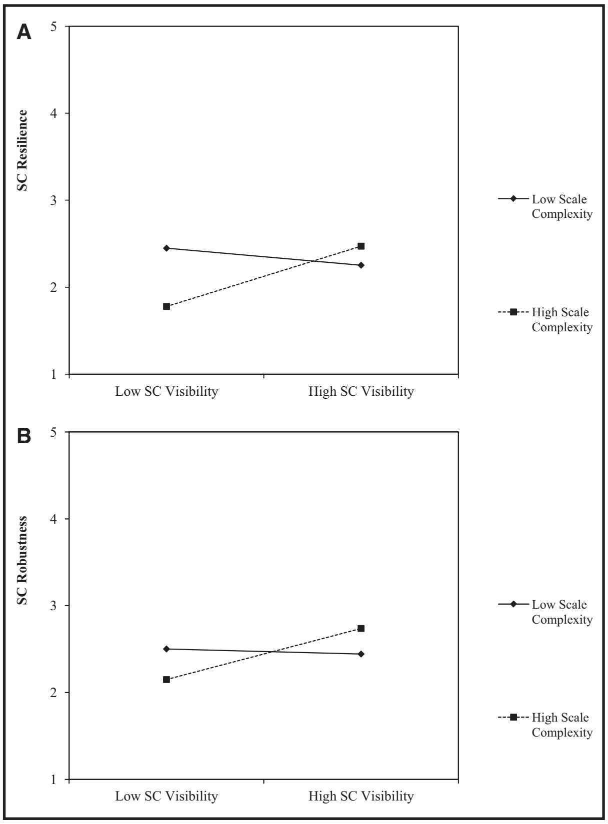
Significance at *$p < .05$, **$p < .01$, ***$p < .001$, †$p < .10$; coefficients are standardized.

Third, although the existence of a supply chain visibility capability may drive performance in terms of resilience and robustness, the effect is contingent upon certain aspects of supply base complexity (see Figure 1); and the use of a contingent RBV perspective allows us to understand how and when investments in a supply chain visibility capability are valuable (Aragón-Correa & Sharma, 2003). As investments in visibility may be costly, we identify the conditions under which investments are worthwhile in delivering improved resilience or robustness. We find that the four dimensions of complexity in this study—scale, geographic dispersion, delivery, and differentiation—have different contingency effects on the relationship between supply chain visibility and both resilience and robustness. In this study, we identify scale, in terms of the number of suppliers, as the strongest aspect of supply complexity in moderating the relationship between supply visibility and both resilience and robustness. As an organization has to manage a greater number of suppliers, relationships will most likely become more transactional in nature, therefore visibility capabilities can allow organizations to better understand the inherent strengths and weaknesses in the system and thereby create greater supply chain resilience and robustness. However, for the other dimensions of supply base complexity—geographic dispersion, delivery, and differentiation—a noncontingent effect is identified. Supply chain visibility positively impacts supply chain resilience and robustness regardless of the geographic dispersion or concentration of suppliers; regardless of the reliability and lead-time length of suppliers; and regardless of the level of differentiation or similarity of suppliers. This demonstrates the importance of supply chain visibility as a capability to reduce the impact of supply chain disruptions.

Managerial Implications

This study offers a number of useful implications for supply chain and procurement managers. First, our findings demonstrate that investments in visibility capabilities may generate differential value depending on key contextual factors. For organizations operating within simple supply chains (for example, ones that have few suppliers), the marginal benefits of increased supply chain resilience or robustness may be outweighed by the significant investments required. Conversely, for organizations operating in complex supply chains (i.e., ones typified by large numbers of suppliers), we find that investments in supply visibility capabilities create resilience and robustness and therefore

FIGURE 2
(a) Interaction Effects of Visibility and Scale Complexity on Supply Chain Resilience. (b) Interaction Effects of Visibility and Scale Complexity on Supply Chain Robustness



typically represent a good return on (the often high) investment. For those organizations that operate between these two extremes, moderate investment in supply chain visibility may be most appropriate, with the focus of such investments influenced by which facet of complexity is most prevalent in their supply chains. This contingent perspective allows more effective decision-making regarding levels of risk management investment depending on the contexts within which organizations operate. However, as we find the other dimensions of supply base complexity to have noncontingent effects, supply chain managers can invest in a visibility capability regardless of the geographic spread of suppliers, the reliability and lead-times of suppliers, and the differentiation of suppliers in the knowledge that visibility will enhance resilience and robustness.

Second, by demonstrating that supply chain resilience and robustness are distinct concepts, we provide managers with insights into the fact that investment decisions have different implications for the way in which the postinvestment supply chain will operate. Some managers may feel it is more suitable to invest heavily in withstanding disruptions and therefore making their supply chains more robust to disruptions. Others may instead focus on ensuring that if and when a disruption occurs, their organization is able to recover quickly and with minimal disruption, therefore making their supply chains more resilient. Trade-offs between these different investments may be influenced by performance objectives, where robustness may support supply chains that rely heavily on dependability, whereas resilience may be more suited to organizations that compete on speed and flexibility.

Limitations and Directions for Future Research

The limitations and potential areas for future research are outlined below. As is common with cross-sectional survey design, this study was constrained by the use of single respondents. While our approach provides strong insights into both the direct and contingent effects of visibility, future research may examine the development of visibility as a capability and how it depends on critical resources and contingent conditions. Due to the nature of the survey respondents, we could not test for a further measure of complexity (supplier–supplier relationships) as this would rely on network data (Choi & Krause, 2006). However, this would be a worthwhile approach for future research.

In addition, future research could examine other resources or capabilities which might enhance resilience or robustness. For example, the impact of flexibility, adaptability, or intra-organizational management capabilities (Pettit, Fiksel & Croxton, 2010) could be explored. Furthermore, survey research could examine the effect of the four capabilities explored in Jüttner and Maklan's (2011) case research—visibility, collaboration, velocity, and flexibility—on both resilience and robustness. Future studies could also extend our model to include further theoretical lenses. In particular, we suggest that extensions of the resource-based view, such as the relational and knowledge-based views, may provide further insights into the antecedents of resilience and robustness.

Finally, where supply complexity is utilized as a contingent factor within this research, other factors which might moderate the relationship between visibility and resilience and robustness could be examined in future research.

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Emma Brandon-Jones (Ph.D., University of Bath) is a lecturer in operations and supply management at Manchester Business School at the University of Manchester in Manchester, England (United Kingdom). Her research interests include supply chain risk management, sustainable operations and supply chain management, and the emergence of new trends in outsourcing such as on-shoring and re-shoring. One of her current projects investigates the factors influencing recovery from supply chain disruptions; a second project explores shareholder reactions to on-shoring announcements. Dr. Brandon-Jones' work has been published in the *International Journal of Operations and Production Management.*

Brian Squire (Ph.D., University of Bath) is a professor of operations management at the School of Management at the University of Bath in Bath, England (United Kingdom). His research is concerned broadly with the design and management of operations and supply chains for resilience, innovation, and sustainability. Increasingly, Dr. Squire has become interested in using multiple methods across multiple units of analysis. His research has been published in a wide range of journals that include the *British Journal of Management*, *Production & Operations Management*, and the *International Journal of Operations and Production Management*.

Chad W. Autry (Ph.D., University of Oklahoma) is the Taylor Associate Professor of Supply Chain Management at the University of Tennessee in Knoxville, Tennessee. His research focuses on relational, technological, and process connectivity in the supply chain. In particular, he is exploring multiple forms of connectivity occurring simultaneously, as well as the impacts of connectivity on innovation, process improvements, and financial outcomes. The current article is the 50th peer-reviewed paper accepted for publication authored or coauthored by Dr. Autry. He serves as a Co-Editor-in-Chief for the *Journal of Supply Chain Management*.

Kenneth J. Petersen (Ph.D., Michigan State University) is the John H. "Red" Dove Professor of Supply Chain Management at the University of Tennessee in Knoxville, Tennessee. He has wide-ranging research interests within the field of supply chain management and its related disciplines. His work has been published in, among other outlets, the *Academy of Management Journal*, *Decision Sciences*, the *Journal of Operations Management*, the *California Management Review*, the *Journal of Product Innovation Management*, and the *Journal of Business Research*. Dr. Petersen serves as an Associate Editor for the *Journal of Business Logistics*, the *Journal of Operations Management*, and the *Journal of Supply Chain Management*.