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Supply chain resilience: role of complexities and strategies

Angappa Gunasekaran[a]*, Nachiappan Subramanian[b] and Shams Rahman[c]

[a]*Department of Decision and Information Sciences, Charlton College of Business, University of Massachusetts Dartmouth, North Dartmouth, MA, USA;* [b]*Nottingham University Business School China, University of Nottingham, Ningbo, China;* [c]*School of Business IT and Logistics, RMIT University, Melbourne, Australia*

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This article introduces the relationship between complexities and proactive management practices in supply chain resilience, particularly due to global sourcing (GS) strategies. The main objectives of this paper are as follows: (i) explain the various aspects of GS rather than reporting the trends and implications described in the literature, (ii) view GS in terms of complexity theory and (iii) investigate the resilience of supply chain due to GS complexity and suggest strategies to overcome complexities. We propose a GS resilience framework for future researchers to analyse the impact of GS complexity factors on supply chain resilience with respect to three outcomes: (i) risk and innovation, (ii) benefit in terms of sales promotion and (iii) challenges and responsiveness. Based on the framework, this introductory article summarises the papers appear in this special issue. This article would be useful to researchers and practitioners to further explore the role of complexities, proactive management strategies on GS resilience.

Keywords: resilience; global sourcing; complexities; strategies; framework

1. Introduction

Both manufacturing and services have started sourcing from different countries in order to gain competitive advantage through effective supply chain management strategies. The motivations for sourcing are to achieve technological innovation, shorten product life cycle, reduce end product prices and total cost of ownership, reduce number of suppliers and establish strategic relationship. The major benefits for sourcing in different countries are reduction in material, labour, component service and capital investment cost. To a certain extent, supply chains can improve service reliability and order lead time. However, supply chains are subjected to numerous challenges such as dependency on few suppliers, inability to react quickly to uncertainties, nature of buyer–supplier relationships and the channel they choose to do transactions amongst various other constraints. In addition to the above challenges, supply chains are also susceptible to other artificial and natural calamities. In a broader perspective, these challenges add complexity to their products and processes. In order to overcome the complexities and minimise and avoid vulnerability, different strategies are to be adapted by supply chain managers. This motivated various researchers to study the potential pathways to enhance supply chain resilience by understanding the importance of supply chain risk or vulnerability factors. International journal of production research (IJPR) is profound and pioneer in discussing various emerging challenges with respect to production and operations management research until now. More than half a century journey of IJPR, it has published dedicated special issues in the context of risk and resilience. One among the recent special issue is on the topic creating resilient small and medium enterprises. IJPR is about to publish its 55th anniversary issue and still it prefers to allocate space to emerging researches and it is evident that this special issue explores further research on resilience along the context of global sourcing (GS). This editorial piece proposes a GS resilience framework, summarises the special issue papers against the proposed framework and suggests future research directions.

2. GS and complexities

GS is defined as management of R&D, manufacturing and marketing interfaces on a global basis to link various production units with particular market such that the firm can exploit both its own advantages and the comparative advantages of various countries (Kotabe 1992). GS is an old trading concept and its evolution can be viewed in two phases. In the

*Corresponding author. Email: agunasekaran@umassd.edu

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first phase, trade flows were centred on goods and that to/from developed countries, whereas in the second phase services, information and knowledge are sourced from emerging and transition economies (Baldwin and Martin 1999).

GS is a term frequently used by practitioners than academicians. It is a relative term and can be viewed in terms of comparative price level which is the ratio of purchasing-power parity to the exchange rate. Purchasing power parity is the number of currency unit required to buy goods equivalent to what can be bought with one unit of the currency of the base country or with one unit of the common currency of a group of countries. Hence, GS is a coordination of integrated procurement process of world-wide business units for acquisition of both goods and services from suppliers in countries with a lower comparative price level compared to the home country of the buying firm (Lockstrom 2007).

Generally, international purchasing objectives of focal companies are short sighted without any long-term orientation and it has not been adequately institutionalised (Lockstrom 2007). Major reasons for non-institutionalisation are lower cost, non-availability of domestic suppliers, exchange rates, tax rates and increased price levels in the home market. International purchasing is also considered as a reactive process rather than a proactive initiative in order to cope with market forces and increased levels of outsourcing made focal company to strategically orchestrate supplier's activities (Agrawal and Nahmias 1997; Dyer 1996; Fine 1998; Trent and Monczka 2003).

It is interesting to note that complexity within the focal firm's country of operations encouraged them to engage in GS. Starr (1984) identifies domestic complexity factors as an important driver for international sourcing and classified them under four major categories such as political, socio-economic, technological and macro-economic factors. Trade barriers, tax rates and labour laws are few issues within political category, similarly educational levels, language proficiency, cultural openness are few factors within socio-economic category, new innovations, wireless and information technologies, new and improved means of transportation are well-known factors within technological category, productivity and growth of markets, wage, tax and interest rates, foreign direct investments are prominent among others under macro-economic category.

To overcome domestic complexity factors focal firms are attracted towards international purchasing because of number of attractions such as acquire advanced production technology, shortened product life cycle and lower price. However, in many occasions focal firms misread the above advantages without preparing themselves to deal with intangible factors associated with international purchasing (Bozarth et al. 1998; Trent and Monczka 2002). The noteworthy attractions are gain in total cost, lower material cost and labour cost than others and mostly focal firms procured energy, raw materials, food and telecom products (Lockstrom 2007).

As per the well-known transaction cost analysis theory, it is better to source complex supplies internally rather than from external suppliers. Goods are sourced to a 70% greater extent than services in low-cost countries. This is most likely due to the complex nature of services. Services also involve a higher degree of social interaction, which is sometimes restricted by language and cultural barriers, thus further complicating the issue (Vargo and Lusch 2004). But it is expected that service would also be sourced more in future and it would be at the similar level of goods sourcing.

There are contradictory views regarding domestic sourcing. One school of thought suggests to procure internationally to avoid local complexity and other thought recommend to procure complex supplies in domestic market. Similarly recent study by Shih (2014) discussed potential complexities and challenges in reshoring. However in any case, focal firms should understand the challenges regarding procurement to deal with different types of complexities both in terms of process and product. Process complexities include upstream and downstream processes including supply and market side factors such as continuous monitoring and intelligence, supply chain transparency, supply chain collaboration and supply chain design and development. Product complexity refers to product design such as functional complexity, product newness and other commercial constraints (Barclay and Dann 2000; Christopher and Peck 2004; Subramanian and Rahman 2014).

2.1 *Continuous monitoring and intelligence*

It is obvious that continuous monitoring would increase the visibility of the supply chain as well as it prepares supply chain members to deal with uncertainties (Ponomarov and Holcomb 2009). Similarly, knowledge accumulation and use of big data could help firms to develop intelligence to be proactive to reduce supply chain complexities. Moreover, the Internet of Things (IoT) has a major role to play in continuous monitoring of supply chain functions and increase visibility in order to reduce the negative impact of uncertainties.

2.2 *Supply chain transparency*

Transparent supply chain will reduce complexity by ensuring end to end visibility, order processing, inventory status, transportation and distribution with the actual primary information without the need of predicted data. Some of the

potential ways suggested by researchers to improve transparency in supply chain are training professionals, cross fertilise learning from suppliers, collaborate with other buyers to drive change in the common buyers, use network to reach lower tier suppliers and adapt according to local realities (Plambeck, Lee, and Yatsko 2012). The real-time data collection and analysis with the help of enterprise information systems will enhance the transparency in supply chains and in turn better control of supply chain operations. Nevertheless, a clearly articulated performance measures and metrics and their use in managing the activities and resource allocation would support the transparency in a supply chain. Therefore, further research is required in the area of performance measures and metrics given the advances in big data and business analytics and the IoT.

2.3 *Supply chain collaboration*

Collaboration ensures exchange of information between supply chain partners and reduces uncertainties and complexities. Exchange of information in all activities in a process along with necessary relationship will certainly help supply chain to reduce complexity (Christopher and Peck 2004). Partnership is a key for successful supply chain operations, especially in a global enterprise environment. The supply chain actors need to share information in real time using one of the enterprise resource planning (ERP) systems in order to enhance the collaboration in supply chain. Collaboration through appropriate partnership and information sharing in the early stage of the supply chain operations (upstream side) would reduce the uncertainties and complexities. For example, collaboration during the product and supply chain design will reduce the complexities and uncertainties in the supply chain operations.

2.4 *Supply chain design and development*

Supply design and development have strong links with complexities in terms of number of suppliers to a buyer and huge number of interacting pairs. Complexities depend on the supply chain structure and informational elements (Ponomarov and Holcomb 2009). The complexities and uncertainties can be overcome by optimal supply chain configuration in terms integrating the activities of number of tiers of suppliers and customers and the number of partnering firms at each tier. Again, these depend upon the exchange of information and goods. Identifying the right suppliers or partnering firms, based on appropriate criteria will play a major role in supply chain design and development. Also, in-house and sub-contracting (outsourcing) will determine the complexity and uncertainties of a supply chain. Appropriate models and empirical research should be conducted in order to determine the criteria for optimal supply chain configuration and in turn reduce the uncertainties and complexities in a supply chain.

2.5 *Product design*

Complexity in product design raises from structural complexity such as number of component, number of process stages, degree of inter-relatedness, number of technologies, technological difficulty, number of functions, performance criteria, degree of specificity, appearance, product newness, development cost and time, adverse legislation, competition, product life and product cost (Barclay and Dann 2000).

It is imperative to analyse complexities in GS and recent studies indicate the need of additional research to model, design and analyse complex supply chains to understand link between GS and complexities (Colicchia and Strozzi 2012). Similarly, it is also important to propose performance measures to complex supply chain. Early involvement of suppliers and partnering firms in the design of products can overcome the supply chain uncertainties and complexities. The design team should be multidisciplinary involving people from all the major functional areas and leveraging the various design strategies and technologies including the concurrent engineering, design function deployment and 3D modelling. Moreover, 3D printers (additive manufacturing) could support the product design and prototyping in order to reduce supply chain complexities and uncertainties. More research is required to study the role of design strategies and technologies in reducing the complexities and uncertainties in supply chains.

3. Supply chain resilience

Supply chain resilience is defined as ‘the capacity for an enterprise or set of business entities to survive, adapt, and grow in the face of turbulent change’ (Fiksel et al. 2015). Business entities’ ability to anticipate the impact would be a valuable skill set if they are to respond and recover within a short span of time until the next major event will distinguish the high-performance businesses from the rest. Those organisations with resilience built into their supply chains should have the sufficient capabilities not only to reduce exposure to transportation disruptions, but also reduce exposure

to a wide range of supply disruptions that might arise when the next big crisis hits (Accenture 2010; Ponomarov and Holcomb 2009; Spiegler, Naim, and Wikner 2012; Tukamuhabwa, Stevenson, and Busby 2015).

However, risk is different from resilience and it is defined as the probability of a negative event to occur (Knight 1921). Risk management entails business entities to examine all possible outcomes of a project or process, then weighing the potential returns against the potential risks of the investment (Ho et al. 2015). In many applications, risks can be quantified based on historical data, but evaluating risks require assumptions based on subjective information. From this perspective, risk is different from uncertainty in a sense that it is quantifiable (Ho et al. 2015). Various causes of risks to focal firms are due to the presence of huge number of suppliers that would increase the probability of unreliable delivery, dense relations in supply base, suppliers vulnerable to demand fluctuation, information overload among suppliers, increased probability of exposure to undesirable events (Accenture 2010). From a theoretical perspective, complexity and risk are closely related concepts. According to Luhmann (1995), because complexity usually accompanies high degrees of freedom in a system from a control-theoretic perspective, managers cannot attempt to control all elements in the system simultaneously but need to address them selectively in an incremental approach. The greatest weakness of risk management is its inability to adequately characterise low-probability, high-consequence events (Corominas 2013). The traditional risk assessment approach cannot deal with unforeseeable events. An efficient and adaptable supply chain risk management strategy can be the difference between survival and success. Moreover, in a prolonged global downturn such as the current one, a resilient supply chain strategy can yield significant competitive advantage.

Several gaps exist in resilient supply chain research such as the lack of conceptualisation of the holistic view of resilience, nature of relationships between various risks and their implications for supply chain management, as well as appropriate models and methodologies to manage resilience (Bhamra, Dani, and Burnard 2011; Gunasekaran, Rai, and Griffin 2011; Ponomarov and Holcomb 2009). Few studies proposed conceptual frameworks to integrate logistical capabilities and supply chain resilience. However, it is hard to identify a study which presents a resilience framework in terms of complexities and proactive management strategies. Furthermore, few studies focussed solely on lead time aspects at the supply side and did not consider from the complexity point of view (Colicchia, Dallari, and Melacini 2010). In global supply chain operations, there are several complexities and uncertainties in addition to lead time because of third party logistics service providers.

4. GS complexity and resilience

GS is associated with endless list of potential risks such as quality defects, high inventory levels and delays which are manageable from an operational perspective. However, risks at a higher level are not always particularly easy to assess (i.e. uncertainty). Similarly external environment risks such as next natural disaster, political turmoil, terrorist attack, labour unrest or other event are impossible to predict and they might cause havoc to firms and supply chains. Occurrence of negative events is not occasional, for example, disruption of supply may be caused by fire or strike at a supplier's plant. Nishiguchi and Beaudet (1998) illustrated the strategy taken by Toyota to alleviate such risk. Likewise, suppliers may become competitors by acquiring the focal firm's technological core knowledge. Bleeke and Ernst (1995) discussed how Thomson Consumer Electronics was first a supplier to JVC and then eventually moved into the JVC's market as a competitor after acquiring the technologies from JVC. Volatilities in market are also important causes of complexity which may have undesirable effects. According to Emerson and Piramuthu (2004), mismatches in demand and supply arise primarily due to market volatility. And, there are opportunity costs that are associated with these mismatches. Examples include decrease in quarterly earnings in 1996 by $900 million for general motors due to 18-day labour strike at a brake supplier factory that idled workers at 26 assembly plants. Similarly, Boeing's $2.6 billion loss in 1997 due to failure of two key suppliers to deliver critical parts on time likewise Ericsson's loss of three market-share points against Nokia in 2000 that forced exit from handset market due to fire in Philips Electronics plant in New Mexico leading to disruptions in supplies of chips for key new handset (Abbasi 2008).

Cost-cutting without thought for long-term strategy does not always deliver the desired results. Cheaper labour costs, for example, may make developing countries look like attractive partner options, but political or infrastructure-related uncertainty can make them costlier options in the long term. In fact, practitioners feel that cost-reduction programmes may have actually reduced their supply chain's resilience (Fiksel et al. 2015). David Simchi-Levi, a supply chain expert at Massachusetts Institute of Technology, told the Supply Chain Digest that if oil prices rose from US$100 to $US150/barrel, total supply chain costs could rise by 3%. The impact of such an increase on a company's bottom line would be huge. He also emphasised transport costs which become more important, relative to production and facility costs, as oil prices raise. Disruption to the supply chain resulting from labour disputes, information technology (IT) or utility failure, and intellectual property (IP) infringements, labour disputes, IP protection or utility failure were concerns for companies

in the past, they have been well and truly replaced by factors such as currency and energy price fluctuations, doubts about customer confidence, supplier insolvency and protectionism (Simchi-Levi and Fine 2010). Pressure is building on firms and supply chains to increase its supply chain resilience.

Typical sourcing complexities arise due to differences in buyer–supplier capabilities, processes and miscommunication, rate of change, volatility and managerial perception of uncertainty. Similarly type of relationship based on asset specificity is also an important issue. For standardised, low-value supplies, such as nuts and bolts, where a large number of suppliers are competing on price, a transactional relationship is preferred. On the other hand, for supplies with high asset specificity, a strategic relationship is the preferred type of relationship if not producing in-house (Murray 2001). Types of channel used to source materials matters to most of the firms. For instance, if a product is of highly complex in nature, then *direct purchasing* from LCC supplier is preferred, followed by purchasing from LCC supplier through *foreign subsidiary*. However, if a product is relatively less complex then purchasing from LCC through *suppliers subsidiary* in home country is preferred, and if a product is quite common and well known then purchasing through third party intermediary is preferred. Generally, low complex products are purchased through international procurement office (IPO) (Lockstrom 2007).

5. Proactive management strategies

Firms and supply chains need to be proactive to strategically deal with complexity. Few studies generally conceptualised the trade-off effect of proactive elements 'efficiency-flexibility-resilience' in disruption management (Ivanov, Sokolov, and Dolgui 2014). The elements of the proactive management are explained below:

5.1 *Flexibility*

Flexibility allows companies to react faster to select suitable option during both positive and negative influences of the external environment As a result, companies with more flexibility realign resources quickly than their competitors (Ponomarov and Holcomb 2009), gain market share at the expense of the industry titans to remain strong in the future (Naisbitt 1994).

5.2 *Speed and responsiveness*

Speed and responsiveness is all about how quick firms are able to use information to react and respond to unpredictable changes in demand and supply (Christopher and Peck 2004). Ohmae (1985) and Trent and Monczka (2002, 2005) stress the need for speed in order to keep up with the pace characterising the current business environment. Responsiveness is all about how firms are capable to adapt to local consumer demands? Today, practices have significantly changed and buying firms have more diverse range of relationships with their suppliers. The trend is indicating that most companies will continue to reduce their suppliers and instead developing the relationships with preferred suppliers (Trent and Monczka 2002). Early supplier involvement, cross-functional collaboration and spend consolidation have proved to be 'key success factors' to purchasing and supply management (Dobler and Burt 1996; Trent and Monczka 2002). Sole-sourcing and using low-cost country suppliers are great strategies for reducing costs, but need to be balanced to create flexibility. A more streamlined process for bringing new suppliers on board allows companies to quickly find and use new sources of commodity goods in an emergency. And for critical materials, a diversified supplier strategy may offer the flexibility needed to mitigate risk (Accenture 2010).

5.3 *Efficiency*

Efficiency decides the economies of scale and comparative advantage. Firms as of today have primarily focused on improving activities with a relatively narrow horizontal and vertical range in the organisation, simply because it is much more difficult to implement organisational changes that span multiple functional units, multiple business units, or even multiple firms. Efficiency made majority of the firms to experience positive impact on total cost, material costs, labour costs and quality. Naturally, these advantages are offset by increased transportation costs, inventory costs and order lead time, due to the increased geographic distances.

5.4 *Stages to manage complexities with respect to GS strategies*

To manage GS and avoid complexities basic steps as shown in Figure 1 by focal firms before they engage in GS are explained below.

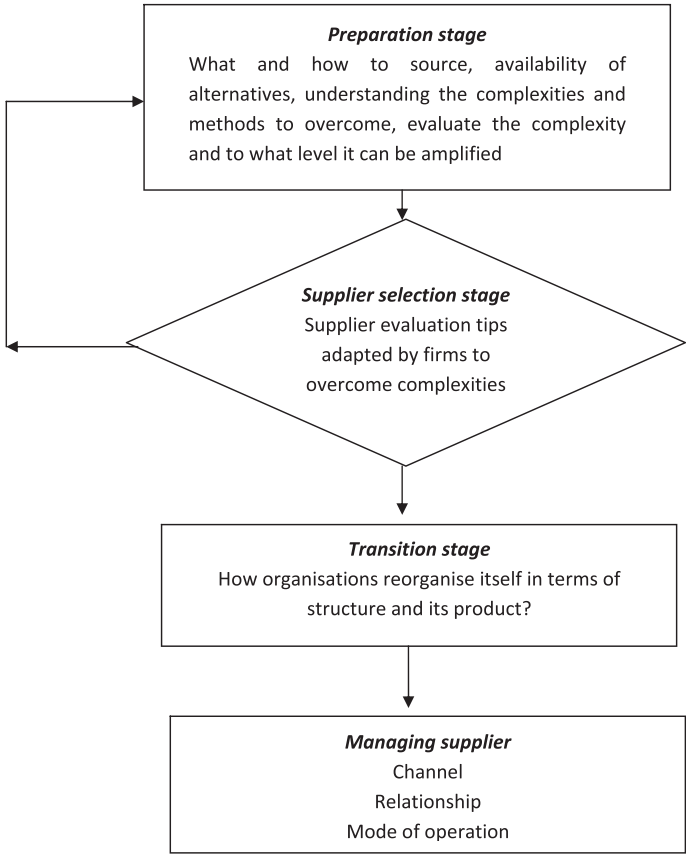

Figure 1. Supply chain capability management stages in GS.

5.4.1 *Preparation stage*

Focal firms that are planning to engage with GS have to be prepared by ticking the checklist as follows: (i) determine the total landed cost; (ii) assess internally to exploit opportunities and neutralise threats and global capacity planning to forecast future needs of internal customer; (iii) evaluate options for purchasing channel such as initially establishing IPO; (iv) assess GS initiative and benchmark with peers; (v) decide sourcing location based on the importance tagged towards transportation and inventory cost; (vi) check whether focal firms have implemented total cost management approaches in sourcing process and (vii) how far they are flexible in order to meet fluctuating demands.

5.4.2 *Supplier selection stage*

The main criteria for supplier selection are to (i) identify qualified suppliers and (ii) negotiate with the suppliers. Normally focal firms need to assess both supplier capacity (production capacity) and capability (new product development capability) while selecting suppliers. The selection criteria for suppliers in the twenty-first century supply chain operations should include: quality, flexibility, dependability, responsiveness and cost. Also, they should include the IT and knowledge management capacity.

5.4.3 *Transition stage*

Once the focal firms have right suppliers in place then they need to start business process redesigns based on onsite supplier management and face to face communication. If possible whatever the product they procure they need to evaluate product redesigns to reduce the need of capital-intense automation equipment as well as increase the degree to labour content and vice versa.

5.4.4 *Managing suppliers*

Suppliers' management depends on three aspects such as channel, relationship and mode of operations.

In deciding suitable channel that could be having a dedicated personnel specifically addressing GS or having contracted third party GS services and if the above two are not possible then the firms can think about IPO.

Relationship is another element that needs to be considered by focal firms through formulation of long-term strategic contract and opting to share technologies. Close relationship and open communication between the focal company and its suppliers might increase suppliers' responsiveness. Similarly relationship depends on what information they are sharing with suppliers and how they do this. Again focal company need to be cautious by seriously viewing if there is any cooperative supplier–supplier relationship which may often stray into collusion. Somewhat protecting mechanisms would be enforcing agreements where there are possibilities of potential sources of friction.

Execution of contract between buyers and suppliers is the most common procedure to materialise the purchase of parts, sub-systems or assemblies and services. To avoid conflicts it would be safe for focal company to include cost of coordinating friction. Especially frictions arise primarily from the focal company's interaction with suppliers as external entities to obtain needed inflow of materials, parts and services. The focal company could be proactive if they include specific set of transaction cost to cover order placement and preparation, transportation of the goods, inspection, and return of parts, follow-up and correction of orders. This is certainly helpful for developing and maintaining exchange relationship, monitoring exchange behaviours and guarding against opportunism in an exchange situation. If the collaboration between buyers and several suppliers and if the two suppliers supplying the same focal company exchange technological information and commit their resources for joint activities then the likelihood of achieving innovation increases. Level of differentiation among suppliers could also tap many dimensions including geographical location, culture, supplier size, unionised or not, technical sophistication, industry and so on. One more measure to gauge interconnectedness is to assess the supplier associations in terms of participation in annual supplier awards, trade associations and similar activities.

6. GS resilience framework relating complexities and strategies

6.1 *GS complexities and strategies*

In the context of GS complexity has a major impact on supply chain performance. It is one of the key drivers of excess cost as well as inventory in the system. Furthermore, it impacts flexibility, resilience and responsiveness of the supply chains. According to Hoole (2006), complexity makes a supply chain inflexible and inefficient. It also hampers on-time delivery and creates problems for product quality. The more complex the supply chain, the greater the possibility it will fail in one or more of its functions, and failures jeopardise a company's relationships with customers. In spite of this, most supply chains are not strategically aimed to reduce supply chain complexity. Literature suggests that complexity management at supply chain level did not receive enough attention among researchers most studies deal with the reduction of complexities at firm level (Pettit et al. 2013).

The nature of relationship (see Figure 2) between complexities and proactive management strategies on supply chain resilience has different outcomes such as risk and innovation, benefits, and challenges and responsiveness. If the association between complexity and resilience is stronger than proactive management strategies the net possible outcome would be risk to the focal companies. Certainly customers will not pay for additional cost and companies need to reduce complexity. Also another school of thought suggests that complexities will induce firms to identify ways through innovating new products and processes. Proactive companies will try to match the strength of association between complexities with resilience and proactive strategies with resilience to gather benefits. Long-term oriented companies would try to

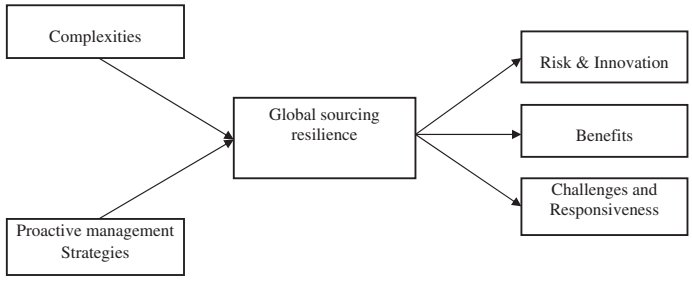

Figure 2. GS resilience framework.

build adequate proactive strategies to overcome complexities to be responsive and exploit the opportunities the customers will pay for.

6.2 *Performance metrics for supply chain resilience*

A recent study by Fiksel et al. (2015) suggests several factors to capture vulnerability and supply chain capability. The major factors under vulnerability are turbulence, deliberate threats, external pressures, resource limits, sensitivity and connectivity. Similarly, supply chain capability factors suggested are flexibility in sourcing, flexibility in manufacturing, flexibility in order fulfilment, capacity, efficiency, visibility, adaptability, anticipation, recovery, dispersion, collaboration, organisation, market position, security, financial strength and product stewardship.

Overall the factors help practitioners to deal with cause and effect of resilience but to be precise it is very hard how to measure each factor under vulnerability and capability categories both at firm and supply chain level. One among the potential area for future researchers is to develop framework at operational level that could suggest several performance measures with respect to firm, supply chain under different industry and country contexts (Munoz and Dunbar 2015).

On the complexity point of view it is still not clear how to measure product and process complexities. Especially, given various potential elements within product and process complexities there are no specific measures or methods available to capture performance at the firm and supply chain level. Similarly it is not so implicit how to measure the end effect of resilience risks, benefits and several other challenges. All these pave way for future researchers to concentrate performance measures aspects.

7. Overview of special issue papers

We received 29 manuscript submissions in response to our initial call. After rigorous review process eight papers are accepted. In this section, the accepted papers are summarised against the proposed resilience framework. Out of eight papers, five papers address some aspects of proactive management strategies such as use of multiple suppliers, choice of contract, flexibility, versatility, responsiveness, relationship strategies, innovation capabilities, organisational awareness and relational behaviour strategies. Out of the three remaining papers, one paper deals with complexity issues and the rest two discusses the method to deal with risks and classification of risks based on supply chain reference operations model.

Merzifonluoglu et al. discuss the importance of multiple suppliers and backup suppliers to avoid risk in firms sourcing decision. The authors consider two important strategic remedies for increasing supply chain resilience such as (i) procuring from multiple suppliers and (ii) utilising option contracts. The authors propose a mean-risk optimisation model under news vendor problem settings with multiple suppliers and study sensitivity of firms sourcing strategies to risk, shortage cost, demand uncertainty, salvage value and capacity reserve options. The paper proposes a sample average approximation method to obtain near optimal solutions under any random distribution of supplier reliabilities and customer demand.

Alblas and Jayaram examine the design flexibilities and its impact on the firms design resilience. The basic research question of their study is how firms should organise in order to accommodate different type of flexibilities. Authors use ambidextrous and flexibility theory approaches to suggest key drivers of innovative projects design resilience. The main contribution of this paper is the characterisation of design resilience using measures such as versatility and responsiveness. This paper also deals with the classification of four categories of flexibilities and their relationships with design resilience and operationalisation of design resilience in the context of new product development.

Sofitra et al. analysed the co-evolution of supply network relationship. The major objective of their study is to investigate specific relationship strategies connection and co-evolution with other relationship strategies in the context of a specific business situation and interaction policies of firms. Authors model firms' interactions using supply network cellular automata and complex adaptive system perspectives. In the future, authors suggest studying the effect of micro-situation settings on macro-behaviour emergent patterns as well to validate the effectiveness of the model using empirical data.

How to mitigate organisation-wide disruptions is the theme of the paper by Brandon-Jones et al. Authors use information processing theory perspective and managerial views to understand the ways to mitigate the impact of frequent disruptions. Authors capture frequency of disruptions using scale, differentiation, delivery and geographic dispersion complexities and test the relationships between frequency of disruption and firm performance. They identify the role of visibility, production capacity, suppliers and firm safety stocks on relationships between frequency of disruption and firm performance.

Using entropy method, Levner and Ptutskin quantitatively assess the information and knowledge related to the risks in hierarchical supply chain. Authors attempt to mimic real supply chain model using graph models to convert information into useful knowledge to reduce and mitigate risks. The challenge of analysing the truncated supply chain model with non-guillotine cuts has been highlighted in this paper.

Rangel et al. classify the type of risks using supply chain operations reference model with respect to five intrinsic management processes. This study emphasises on the lack of consensus regarding risk and difficulties to identify risk in the entire supply chain network. The authors suggest to empirically validating their proposed risk classification scheme as a part of the future research.

Liao and Marsillac develop and empirically test an integrative model linking external knowledge acquisition with supply chain and product innovation flexibilities under the influence of organisational awareness. The paper discusses the importance of human element in preparedness and the influence of knowledge, capability on supply network innovation. To avoid generalisability and timing limitations of the study, authors suggest using longitudinal data in the future. Similarly, authors suggest developing scales to examine the antecedents and performance implications of external knowledge acquisition for service contexts.

Borekci et al. consider triadic network and discuss the importance of relationship with partnering firms and its influence on organisational resilience using multiple cases. Authors specifically test the impact of competitive, co-operative and co-opetitive relational behaviours on triad and triad components. Authors suggest testing the framework and propositions using large-scale survey in several country and industry contexts.

8. Conclusion

The paper introduces the GS concept and its importance to both academicians and practitioners. Even though it is an attractive strategy to practitioners it leads to complexity in long term if it has not been handled well. Complexity will reduce the supply chain resilience and inturn it necessitates organisations to build proactive management strategies to achieve competitive gains through innovation and responsiveness. The paper proposes a GS resilience framework that relates complexities and strategies with the various outcomes. Overall the paper summarises the accepted papers as per the framework and outlines the possible future research directions. Our framework shows that researchers are more concerned about proactive management strategies instead of dealing with various complexity elements as well as we did not find studies that capture the holistic effects.

The following is a list of future research directions on the role of complexities and management strategies in supply chain resilience:

- More accurate frameworks for studying the relationship between complexities and proactive management practices in supply chain resilience will be required together with appropriate empirical validation.
- Further research on GS strategies and their impact on the operational performance and organisational competitiveness will facilitate a better understanding of the complexities and proactive management strategies.
- Factors affecting the supply chain risk and mitigating strategies and techniques or methods need further investigation through suitable modelling and analysis. Also, appropriate case studies and empirical research will strengthen the applications.
- Role of international purchasing and its implications on supply chain resilience requires further research and development as it involves GS and logistics.
- Analytical and simulation models for optimising the GS with appropriate variables and parameters, and performance objectives such as price, quality, cost, flexibility and dependability are essential for the successful implementation of proactive management strategies for resilient supply chain.
- The role of big data and business analytics in continuous monitoring and intelligence of supply chain operations management needs to be investigated in detail. This should assist the selection of suitable suppliers and their development to ensure resilient supply chain operations.
- Defining the supply chain transparency in the context of supply chain resilience and overcoming the complexities and implementing proactive management approaches requires appropriate performance measures and metrics at all levels (strategic, tactical and operational) including financial, non-financial, tangibles and intangibles. This offers a significant scope for further research and applications.
- Applications and the impact of the IoT in logistics operations require a detailed investigation, modelling and analysis. Real-time information sharing and monitoring of supply chain operations using the IoT offers a great opportunity for resilient supply chain development and operations, and therefore this needs further research.

- Optimal supply chain design should be studied further taking into account the complexities, proactive management strategies and resilience of supply chains.
- Product design and complexities play a major role in supply chain resilience and this needs modelling and analysis for optimal product and supply chain network design and supply chain resilience.
- Appropriate mathematical models and empirical research will support better understanding of the factors that will affect the supply chain resilience and minimise the negative impact of various supply chain risks.
- GS presents numerous challenges and opportunities. This requires further research in terms of developing more comprehensive models and empirical studies to determine the factors that will determine the supply chain resilience.
- Frameworks and models to determine the proactive management strategies and methods are essential. For example, the model shown in Figure 1 should be validated through suitable empirical research and analysis.
- An empirical validation of framework presented in Figure 2 presents an excellent avenue for further research.
- Appropriate performance measures and metrics for resilient supply chain will be the fundamental for assessing and determining appropriate remedial actions while facing uncertainties and various supply chain risks.
- Determine the relationship between resilience of suppliers and the resilience of focal firms. Additional empirical research and case studies are required for this.
- The flexibility of supply chain network can support the resilience in supply chain. This needs further modelling and empirical validation.
- Supply chain resilience is closely connected with inventory management and therefore, this has to be well integrated in modelling and analysis of resilient supply chains.
- Innovation and entrepreneurship of suppliers will determine the supply chain resilience and therefore, this requires further empirical analysis.
- Human resource management in GS needs further investigation as it did not receive adequate attention from researchers. For example, research on the type of education, training and performance assessment is required in GS and addressing the complexities and proactive management strategies for resilient supply chain.
- Information sharing is critical in managing supply chain resilience. This requires a framework for optimal information system architecture incorporating radio frequency identification (RFID), IoT and ERP.
- Knowledge management system (KMS) in an integral part of resilient supply chain. This requires further investigation related to suitable KMS for supply chain resilience.

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