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Supply chain resilience: a benchmarking model for vulnerability and capability assessment in the automotive industry

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Abstract
Purpose – The purpose of this study is to evaluate two supply chain resilience key elements of vulnerability and capability in the automotive industry.
Design/methodology/approach – We propose a fuzzy approach for statistical hypothesis testing and analyze two research hypotheses by synthesizing the results of a questionnaire given to 44 companies in the Iranian automotive industry.
Findings – The results indicate that the automotive industry in Iran should: (1) resist five elements of vulnerability, i.e. “external pressures,” “sensitivity,” “connectivity,” “supplier/customer disruptions,” and “resource limits,” and (2) embrace nine elements of capability, i.e. “flexibility in order fulfillment,” “capacity,” “efficiency,” “visibility,” “adaptability,” “recovery,” “dispersion,” “organization,” “market position” and “security” to achieve greater resiliency elasticity in the supply chain.
Originality/value – This is the first study on the supply chain resilience vulnerabilities and capabilities in the Iranian automotive industry.

Keywords Supply chain resilience, Benchmarking, Vulnerability, Capability, Fuzzy logic, Automotive industry
Paper type Research paper

1. Introduction
1.1 Background
Supply chain management involves all activities associated with the flow of goods, money, information and the effective management of these resources across different organizations

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(Tavana *et al.*, 2016; Azevedo *et al.*, 2013; Siddiqui *et al.*, 2012). Although the goal of supply chain management is to achieve the effectiveness of the product flow and increasing supply chain profitability, however, every activity in a supply chain has inherent risk due to the existence of uncertain and vague information and is potentially subject to disturbances, which can affect the performance of the whole system (Pournader *et al.*, 2016).

Quick recovery after a disruption is crucial for the success of any organization. Sheffi and Rice (2005) propound that organizations can decrease the required recovery time by employing the concept of resiliency in the supply chain. Conversely, if an organization fails to quickly and effectively recover after a disruption, the induced risk negatively influences its supply chain resilience (SCRE). As Pettit *et al.* (2013, 2019) state, higher resiliency improves supply chain performance and aids an organization to attain a competitive advantage in the market. Hohenstein *et al.* (2015) elucidate the reason why organizations struggle recovering from disruptions is that they do not have a clear understanding of SCRE, its benefits and even the implementing process. Therefore, enterprises must become aware of what SCRE is and how it maintains supply chain performance in the event of a disruption.

As an organizational term, resiliency describes the capability of an enterprise to preserve effective performance under challenging and emergent circumstances (Bunderson and Sutcliffe, 2002). From a supply chain management perspective, SCRE is the adapting ability of the system to simultaneously face unpredictable events, address disorders and solve them, ensuring operational continuity. In such scenarios, there is a right level of communicability while having control over the organizational functions and operations (Kaviani *et al.*, 2016; Ribeiro and Barbosa-Povoa, 2018). Resilient processes are fast, flexible and capable of changing immediately. Therefore, a resilient supply chain can reconcile its structure in case of disruptions, to recover consequently, or to achieve a better state of supply chain operations (Kamalahmadi and Parast, 2016).

Several authors (i.e. Brandon-Jones *et al.*, 2014; Colicchia *et al.*, 2010; Ribeiro and Barbosa-Povoa, 2018) have described the key elements of SCRE as "vulnerability" and "capability." The vulnerability elements are potential causes of disruptions within or among supply chain members, e.g. delays in information processing, or procurement, while capability factors describe the ability of each supply chain entity to handle the unforeseen situations caused by disruption, e.g. information sharing, multiple sourcing for key inputs or collaboration. Pettit *et al.* (2019) mentioned that capability factors reflect the significant role of the improvement strategies in integrating, reconfiguring and adapting to respond to the changes that could disturb supply chain activities. The relationship between vulnerability and capability elements has been analyzed by some researchers like Peck (2005), Donadoni *et al.* (2019) and Pettit *et al.* (2013). These latter authors, in particular, integrated vulnerability and capability factors into a single framework. Furthermore, Pettit *et al.* (2010) developed a model to assess the resilience of the enterprise supply chain. Their study categorizes vulnerabilities into seven types, including Turbulence, Deliberate Threats, External Pressures, Resource Limits, Sensitivity, Connectivity and Supplier/Customer Disruptions. To counteract these vulnerabilities, the authors identified fourteen supply chain capabilities, such as flexibility in sourcing, flexibility in order fulfillment, capacity, efficiency, visibility, adaptability, anticipation, recovery, dispersion, collaboration, organization, market position, security and financial strength. They concluded, "the balance between vulnerabilities and capabilities must be measured to assess the current level of resilience" (Pettit *et al.*, 2013, p. 46).

1.2 The contribution of this study

Supply chain disruptive events can have both internal and external causes and harm the performance of the whole system. In this study, we considered 21 variables proposed by Pettit *et al.* (2010, 2013) and tried to contribute to the available knowledge in supply SCRE as follows:

(1) The SCRE vulnerabilities and capabilities are empirically evaluated in the automobile parts manufacturing industry of Tehran, Iran.

(2) The possibility of implementing the aforementioned SCRE capabilities is explored, and the evaluation of their effectiveness is discussed as well.

(3) A hybrid fuzzy hypothesis testing approach is utilized to empirically evaluate SCRE vulnerabilities and capabilities.

(4) Because of its empirical nature, this study is expected to represent a stepping-stone in the existing field of knowledge and research in SCRE.

The remainder of the paper is organized as follows. Section 2 presents a comprehensive literature review, encompassing differing definitions and understandings of resilience and evaluating SCRE. Section 3 details the hypotheses in this study. Section 4 describes the analysis in terms of the research procedure, fuzzy hypothesis testing approach and outcomes of this research. The final section concludes and outlines the results of this study, research contributions and suggestions for future research activities.

2. Literature review

This section provides an in-depth literature review in the field of SCRE and its evaluation. In the end, the relevant studies on the SCRE assessment problem will be summarized, and the research gap will be highlighted.

2.1 Resilience in the SC

Resilience concept is defined as the ability of a system to react, adapt and grow when facing turbulent changes (Pettit *et al.*, 2019). It is a crucial characteristic of complex systems, such as organizations, cities and ecosystems, and is currently considered as a must in the objectives of any organizational manager. To understand the concept of SCRE more clearly, first, we need to consider the various trends in the relevant literature. A review of the previous literature shows several definitions for SCRE in diverse disciplines (e.g. Gunasekaran *et al.*, 2015; Ribeiro and Barbosa-Povoa 2018; Pettit *et al.*, 2010, 2013, 2019). As some researchers like Spiegler *et al.* (2012) and Tukamuhabwa *et al.* (2015) express, there is no consensus on the definition of the resilience concept in supply chain management literature. Nonetheless, most scholars agree that the concept of resilience is context and situation-dependent (i.e. social and ecological vulnerability, disaster recovery policies and psychology, and risk management).

A company is as resilient as its supply chain is (Tukamuhabwa *et al.* (2015). Disruptions in the supply chain may originate from various sources, including external sources (e.g. natural disasters) and internal issues (e.g. failure to integrate supply chain operations). In most cases, these accidents occur rapidly and without warning. In many companies, logistics activities, such as the raw materials supply, assembly of components, production and product defects, are the results of external supplier activities. When the risk in the supply chain increases, a company needs to develop logistics, processes and capabilities that enable efficient and effective responses, and the ability to continue normal business activities also increases (Ponomorov and Holcomb, 2009). As it is highlighted by Ribeiro and Barbosa-Povoa (2018), resiliency in SCs has an important role in supply chain operations' effectiveness.

2.2 Evaluating SCRE

Considering the increasing attention to SCRE assessment, we found several studies that try to evaluate the resilience of a supply chain. For instance, from a company's perspective, Sheffi and Rice (2005) discussed the relevance of being able to recover from a disruption quickly. They noted that such ability could be improved by increasing redundancy and enhancing flexibility in the supply chain. They argued that investing in the resiliency of the firm's supply chain would yield numerous additional benefits for day-to-day operations. Ponomarov and Holcomb (2009) proposed an integrated perspective on resilience, which was built starting from the existing literature relating to different disciplines (including developmental psychology and ecosystems). From the extant literature, the authors developed six research propositions, which link resilience to risk and supply chain management. Colicchia *et al.* (2010) analyzed the inbound supply risk in a global sourcing context. They provided numerous approaches that can be adapted to manage risk in such a way that directly enhances and improves SCRE. They also developed a simulation-based framework used to assess the effectiveness of the proposed strategies in a real scenario. Jüttner and Maklan (2011) investigated the relationship between SCRE, vulnerability and risk management. Through three case studies, they found that supply chain risk knowledge has a positive impact on SCRE, as it enhances flexibility, visibility and collaboration in the supply chain. Furthermore, such positive effects were observed both in upstream supplier networks and in distribution channels.

Carvalho *et al.* (2012) carried out a simulation study on a real supply chain in the Portuguese automotive industry. Their analysis aimed at evaluating whether SCRE can be improved using mitigation strategies and if such an improvement could affect the performance of the whole system, in terms of lead-time ratio and total cost. Spiegler *et al.* (2012) explored the concept of SCRE from a system dynamics perspective. Their analysis captures the key features of resilience (e.g. readiness, responsiveness and recovery) and shows that optimum solutions for resilience do not (necessarily) lead to a system that is robust to uncertainties in lead-time; rather, such a system would experience drastic changes in resilience performance if lead-time changes.

Azevedo *et al.* (2013) developed the "ecosilient" index to evaluate the level of resilience and greenness of automotive companies. Their study demonstrated that the resilient paradigm contributes considerably to the competitiveness of companies in the automotive supply chain. A significant contribution to resilience comes from the use of flexible sourcing strategies, which allow switching suppliers. Pettit *et al.* (2013) developed a measurement tool, called Supply Chain Resilience Assessment and Management (SCRAM), to help manage risk through resilience. They validated the model with data from firms, and further identified 311 specific links to use as guides for a resilience improvement process. They also found a correlation between the increase in resilience and improvement in supply chain performance. Brandon-Jones *et al.* (2014) carried out empirical research in 264 UK manufacturing companies to explore the impact of information sharing and connectivity (resources) and visibility (capability) on the resilience of a supply chain. They found a positive relationship, meaning that increased visibility is expected to improve the resilience and robustness of a system.

Roberta Pereira *et al.* (2014) examined the role of procurement activities in identifying and managing intra- and inter-organizational issues that could affect the resilience of a supply chain. In another study, Soni *et al.* (2014) presented a model that considers the key enablers of resilience and their interrelationships. It is expected that managers will use the model as a tool to compare different supply chains. Urciuoli *et al.* (2014) analyzed the resilience of the energy supply chain, with particular attention on how these systems work to enhance their resilience against security threats. They found that the energy supply chains have, in general, a good number of strategies to protect themselves against disruptions; an example of these strategies include flexible contracts, transport capacity planning and safety stocks.

In addition to the surveyed studies, Gunasekaran *et al.* (2015) studied the relationship between complexities and proactive management practices in SCRE, focusing on global sourcing strategies. They suggested a framework to be used by future practitioners when analyzing the impact of global sourcing complexity factors on SCRE. Hohenstein *et al.* (2015) reviewed the concepts of SCRE through the analysis of 67 published studies. Their study indicates the need for a univocal terminology about resilience, as well as for the classification of resilience strategies (proactive vs. reactive) and measurement indexes. Munoz and Dunbar (2015) focused on the quantification of resilience. They simulated the long-run performance of a supply chain subject to disruptions. Each disruption was modeled in terms of frequency, magnitude and supply chain tier affected. The resulting transient responses are measured along with several metrics popular among resilience researchers. They found that individual metrics of resilience are adequate when evaluating the response performance of a single firm, while more measures should be aggregated to evaluate the response of a supply chain. Again, about resilience measurement, Chowdhury and Quaddus (2016) reviewed the existing literature in an attempt to develop a series of indexes to evaluate the readiness, response and recovery capability of a company. At the same time, in their analysis, the authors explored and justified the antecedences of SCRE. Rajesh (2016) identified the metrics for resilience, starting from typical supply chain performance, such as flexibility, quality, responsiveness or productivity. An adapted grey prediction model is used to link these performance indexes to SCRE and estimate its level.

Dabhilkar *et al.* (2016) empirically validated and further analyzed the supply-side resilience capabilities as well as their constituent bundles of practices. They have identified four supply-side resilience capabilities and unearthed a relationship between the practice bundles of the capabilities and recovered operations performance. Fahimnia and Jabbarzadeh (2016) further analyzed the relationship of sustainability-resilience at the supply chain design level. They developed a multi-objective optimization model that could be utilized to perform a dynamic sustainability tradeoff analysis. Furthermore, they suggested the model be used to create a resiliently sustainable supply chain. Kamalahmadi and Parast (2016) provided a summary of the existing research on enterprise and SCRE, including definitions, principles and strategies. Furthermore, Kaviani *et al.* (2016) suggested a way in which to measure SCRE based on a grey system theory approach. They concluded that distribution issues and supply limitations are the most serious vulnerabilities that threaten the case study company located in Iran. Lam and Bai (2016) developed a quality function deployment approach suitable to enhance the resilience of the maritime supply chain. They analyzed three maritime systems, identified their main risks and the possible countermeasures. The approach developed allows prioritizing the interventions a maritime supply chain can implement against risk factors. Pournader *et al.* (2016) presented and tested an analytical model to evaluate the resilience of a supply chain, both as a whole and amongst its tiers. Their findings indicate that there is variation in the resilience ratings between the overall supply chains in Iranian industry firms and their tiers. They also found that system-wide resilience does not necessarily involve the resilience amongst individual tiers.

Table 1 shows a summary of some relevant recent studies in the area of SCRE appraisal.

2.3 Research gaps

The review of the literature given in the previous section reveals the following research gap. Although several studies have proposed frameworks for analyzing the impact of SCRE in the context of the overall supply chain, not many have focused explicitly on the supply chain capabilities and vulnerabilities. To the best of our knowledge, there are very few empirical studies of SCRE in developing countries (Kaviani *et al.*, 2016) and, more specifically, in the Iranian automotive industry (Yazdanparast *et al.*, 2018). Nonetheless, the supply chains in developing countries constitute a significant portion of the world's supply chain, and any vulnerabilities in the developing countries' supply chains will have an impact on the

Table 1.
Summary of new relevant studies on SCRE assessment

Author(s)	Study purpose	Application
Vugrin *et al.* (2011)	Introducing a comprehensive resilience assessment framework, including quantitative and qualitative analysis methodologies	Petrochemical supply chain
Spiegler *et al.* (2012)	Proposing a system dynamics approach using Integral of the Time Absolute Error tool for measuring SCRE	Make-to-stock supply chain
Azevedo *et al.* (2013)	Presenting an Ecosilient Index-based framework to assess the resilience of the supply chain	Automotive supply chain
Pettit *et al.* (2013)	Proposing a quantitative measurement framework "SCRAM" to evaluate the management of SCRE	Seven companies with global supply chains
Chowdhury and Quaddus (2016)	Introducing a hierarchical SCRE measurement model considering quantitative and qualitative approaches	Apparel supply chain
Fahimnia and Jabbarzadeh (2016)	Designing A "resiliently sustainable" supply chain network as a multi-objective optimization model solved by a stochastic fuzzy goal programming approach	Sportswear clothing supply chain
Kaviani *et al.* (2016)	Presenting a grey systems theory approach to SCRE appraisal	Cement supply chain
Papadopoulos *et al.* (2017)	Using the unstructured big data to test a theoretical framework for clarifying resilience in supply chains for sustainability	Disaster supply chain
Maheshwari *et al.* (2017)	Developing a supply chain design optimization model for considering SCRE cost reduction	Biomass to biofuel supply chain
Ivanov (2018)	Employing a simulation-based framework for mitigating the ripple effect in a resilient supply chain	Smartphone supply chain
Yazdanparast *et al.* (2018)	Assessing SCRE applying a novel hybrid Z-number data envelopment analysis and neural network approach	Automotive supply chain
Rajesh (2019)	Proposing a risk management framework for resilient supply chains using a Grey-Verhulst model	Electronics manufacturing supply chain
Hossain *et al.* (2019)	Utilizing a Bayesian network model for supply chain resilience appraisal	Oil and gas supply chain
Shao and Jin (2020)	Applying a system dynamics modeling approach to supply chain resilience evaluation	Lithium supply chain

worldwide supply chain system. In fact, the supply chains in developing countries are more vulnerable because they cannot rely on government safety networks (Prasad *et al.*, 2015). As far as the context of analysis is concerned, only some studies have addressed the issue of resilience in the automotive industry (e.g. Azevedo *et al.*, 2013, 2016). Yet, this industry is typically seen by researchers as a place to develop, introduce and improve supply chain management concepts (Yazdanparast *et al.*, 2018) and frequently becomes the reference for other industrial fields. Besides, the automotive industry is the second most active industry of Iran (after the oil and gas one), accounts for 10% of the GDP of the country and enrolls approximately 700,000 employees (Govindan *et al.*, 2016). In light of the above considerations, the authors believe that it is important to empirically analyze the capabilities and vulnerabilities of SCRE in the context of an automotive company in a developing country.

3. Hypotheses

3.1 Capabilities of SCRE

Modern supply chains are facing many challenges, in addition to their complexity and inherent uncertain natures. These challenges are making supply chains more vulnerable and force decision-makers to design their supply chains more resilient to cope up with this challenge. To this end, supply chains must have resilient capabilities to mitigate and prevent potential disruptions and minimize vulnerability. Many attributes and abilities of resilient supply chain capabilities have been identified in the literature. They include collaboration (Pettit *et al.*, 2010; Jüttner and Maklan, 2011; Zhang *et al.*, 2011), risk management (Zhang *et al.*, 2011), flexibility (Pettit *et al.*, 2010; Jüttner and Maklan, 2011; Zhang *et al.*, 2011), integration, redundancy and transparency (Ponomarov and Holcomb, 2009; Pettit *et al.*, 2010; Jüttner and Maklan, 2011; Zhang *et al.*, 2011).

In literature, some studies have identified the capabilities of SCRE (see Hamel and Valikangas, 2003; Rice and Caniato, 2003; Tang, 2006; Pettit *et al.*, 2010, 2013). In this paper, we consider the list of factors identified by Pettit *et al.*'s (2010), as it is more comprehensive compared to other works. Based on this list, we hypothesized:

H1. Flexibility in sourcing, flexibility in order fulfillment, capacity, efficiency, visibility, adaptability, anticipation, recovery, dispersion, collaboration, organization, market position, security and financial strength are suitable capabilities for the assessment of SCRE in the automotive parts industry of Iran.

3.2 Vulnerabilities of SCRE

Many authors demonstrated empirically that vulnerability and SCRE have conceptual linkage and are relatively close concepts (Gallopín, 2006). It is obvious that SCRE increases as vulnerability decreases and capabilities increase (Pettit *et al.*, 2010). The vulnerability also has a direct relationship with supply chain performance. According to Elleuch *et al.* (2016), vulnerability measures the intensity of impact generated because of the risk in the supply chain. Similarly, Pettit *et al.* (2010) stated that vulnerability is the potential for a system to be affected by internal or external factors. Vulnerability in the SCRE context has been discussed by several scholars in the literature, for instance, to identify drivers of supply chain vulnerability (Peck, 2005; Wagner and Neshat, 2012; Wagner and Bode, 2006) or to find out best practices to minimize vulnerability. Wagner and Neshat (2012) proposed a method to measure vulnerability in supply chains.

In the earlier studies, we found some researches where the vulnerabilities of SCRE are introduced (see Svensson, 2002; Hamel and Valikangas, 2003; Sheffi and Rice, 2005; Peck, 2005; Pettit *et al.*, 2010). As per the previous section, we have considered the Pettit *et al.*'s (2010) list of factors, which appears to be more comprehensive compared to the other works. According to this list, we hypothesized:

H2. Vulnerability indicators such as Turbulence, Deliberate Threats, External Pressures, Resource Limits, Sensitivity, Connectivity and Supplier/Customer Disruptions, are appropriate for SCRE assessment in the automotive parts industry of Iran.

4. Methodology

4.1 Data collection and sample

A questionnaire survey was designed to test the hypotheses developed. The population for this research included 44 active companies in the automotive parts industry in Tehran, Iran. After contacting these companies, all 44 manufacturers agreed to participate in the research project. A questionnaire was designed distributed among the supply chain experts, and 31 useable responses were received. Figure 1 shows the research framework adopted for this study.

The questionnaire designed for the first round was given to the experts, along with the necessary explanations and directions similar to the format used by Pettit *et al.* (2010, 2013).

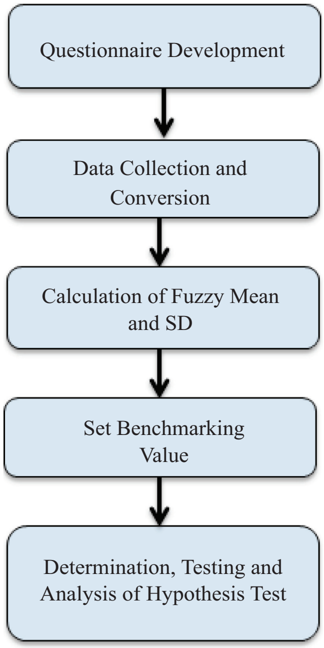

Figure 1.
The research framework of the study

An extraction of variables measured from the literature and their localization using experts' viewpoints and elementary samples were considered to validate the studied criteria, as suggested by Hult and Ferrell (1997). Because the components of variables measured were derived from the research literature, the questionnaire contains validated content.

One out of several ways to establish reliability is to measure internal consistency (Conca *et al.*, 2004). This factor is typically measured by the Cronbach's alpha coefficient. The minimum acceptable value for this ratio should be 0.7, 0.6 and even 0.55 values could be acceptable (Van de Ven and Ferry, 1979). The reliability of the questionnaire, computed using Cronbach's alpha, was 0.84 for general inquiries, 0.73 for questions related to the vulnerability and 0.89 for questions related to the enabling factors. All the values are higher than 0.7, which indicates good reliability.

4.2 Fuzzy hypothesis testing approach

Several aspects of an SC (e.g. supplier's goodwill, variability in demand, or sourcing strategies) are qualitative and quite difficult to evaluate in quantitative terms. Moreover, during the decision-making process, the decision maker's judgments and their subjectivity are also difficult to ponder. Therefore, to evaluate the effectiveness of the selected indices on the SCRE, a fuzzy approach was used for statistical hypothesis testing. The advantage of using fuzzy hypothesis testing over the conventional hypothesis testing approaches is that the former works based on the null and alternative hypotheses, while the latter works solely based on the null hypothesis. Consequently, the fuzzy hypothesis testing technique provides more analytical power to the decision-maker (Parchami *et al.*, 2016).

The fuzzy set theory, developed by Zadeh (1965), is effective in capturing the uncertainty associated with the decision-makers. The fuzzy set theory has also been proven to be an objective method, frequently applied in the evaluation, and making inference systems. As detailed in Figure 1, we developed the questionnaire and got experts' opinions using a Likert scale. Once these data have been collected, we converted them into triangular fuzzy numbers using the values proposed in Table 2.

$$\mu_{\tilde{M}}(x) = \begin{cases} \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

$$-\theta < a \leq b \leq c < \theta$$

After defining the fuzzy sets, fuzzy numbers should be added. To this end, assuming the same importance for all experts' opinions, these values were expressed as triangular fuzzy numbers; $\tilde{X}_i = (X_i^a, X_i^b, X_i^c)$ for linguistic variables is expressed as follows:

$$\tilde{X}_i = \left(X_i^a, X_i^b, X_i^c\right) \tag{2}$$

$$\bar{X}_\alpha = \{x \in R : \mu_{\bar{X}}(x) \geq \alpha\} \tag{3}$$

$$\bar{X}_\alpha^U = Sup\{x \in R : \mu_{\bar{X}}(x) \geq \alpha\} \tag{4}$$

By fuzzy numbers summation, we have the new fuzzy numbers as follows:

$$\tilde{\bar{X}} = \left(\sum_{i=1}^{n} X_i^a, \sum_{i=1}^{n} X_i^b, \sum_{i=1}^{n} X_i^c\right) \tag{5}$$

Then the fuzzy numbers were converted into a crisp value using Eq. (6) as the defuzzification formula:

$$X_i = \frac{\left(X_i^b - X_i^a\right) + \left(X_i^c - X_i^a\right)}{3} + X_i^a \tag{6}$$

Defuzzified numbers represent the independent variables of each questionnaire answered by companies. Thereafter we computed the fuzzy mean of collected experts' opinions. Similarly, as shown in Figure 1, to calculate the fuzzy mean and standard deviation of the variables, we used Eqs. (7) and (8) as given below:

$$\tilde{\bar{X}} = \left(\frac{\sum_{i=1}^{n} X_i^a}{n}, \frac{\sum_{i=1}^{n} X_i^b}{n}, \frac{\sum_{i=1}^{n} X_i^c}{n}\right) \tag{7}$$

Very low 1	Low 2	Medium 3	High 4	Very high 5
(1,1,3)	(1,3,5)	(3,5,7)	(5,7,9)	(7,9,9)

Table 2. The conversion of the Likert scale to fuzzy numbers

$$\tilde{S} = \sqrt{\frac{\frac{\sum_{i=1}^{n}\left[\left(X_i^a - \bar{X}^a\right)^2 + \left(X_i^b - \bar{X}^b\right)^2 + \left(X_i^c - \bar{X}^c\right)^2\right]}{3}}{n-1}} \tag{8}$$

We then needed to compute the lower bound for acceptance of each hypothesis, as mentioned in Figure 1. To this end, we calculate the fuzzy interval estimation of the average phase of each variable and low acceptance of the hypothesis using Eqs. (9) and (10) as given below:

$$(\tilde{\bar{\bar{X}}}_L, \tilde{\bar{\bar{X}}}_U) = \left[(\tilde{\bar{\bar{X}}}^a - (\tilde{\bar{\bar{X}}}^b - \tilde{\bar{\bar{X}}}^a)\alpha), (\tilde{\bar{\bar{X}}}^c - (\tilde{\bar{\bar{X}}}^c - \tilde{\bar{\bar{X}}}^b)\alpha)\right] \alpha \in (0,1) \tag{9}$$

$$\tilde{\bar{\bar{X}}}_U + Z_a(\tilde{s}/\sqrt{n}), Z_{0.95} = 1.64 \tag{10}$$

In the next step, we needed to determine the region of acceptance to decide whether to accept or reject a numerical hypothesis. As recommended by Van de Ven and Ferry (1979), we used 0.7 for fuzzy assumptions as minimum acceptance criteria. Eq. (11) was used to decide whether to reject or accept a research hypothesis:

$$(\tilde{\bar{\bar{X}}}^c - (\tilde{\bar{\bar{X}}}^c - \tilde{\bar{\bar{X}}}^b)\alpha) + Z_a(\tilde{s}/\sqrt{n}) \tag{11}$$

Table 3 shows the procedure used to determine the degree of acceptance of the hypothesis in a fuzzy environment. It is evident from Table 3 that with a higher degree, the hypothesis is validated, and its assurance level is significant.

5. Results and discussion

5.1 Analysis of the outcomes

Table 4 shows the results of hypotheses testing for the factors considered.

Some considerations from the outcomes obtained can be formulated as follows:

(1) Among the empowerment indices, "recovery" got a membership degree of 1.00; thus, its influence on SCRE is fully accepted. This corresponds with Tang (2006), Pettit *et al.* (2010, 2013), Rice and Caniato (2003) and Peck *et al.* (2003). The index of "flexibility in sourcing" with the membership degree of (0.57) is accepted with a medium impact on SCRE; this is consonant with Christopher and Peck (2004) and Peck (2005). Conversely, "anticipation," "financial strength," and "collaboration" with a membership degree of 0.32, 0.26 and 0.15 are not probable to be accepted as significant aspects of SCRE. It should be mentioned that outcomes for "collaboration" show a weak correspondence with Rice and Caniato (2003) and Peck *et al.* (2003). The "financial strength" index is not likely to correspond with Rice and Caniato (2003) or Pettit *et al.* (2010).

(2) Among the indicators of vulnerability, "deliberate threats" turned out to get a membership degree of zero, which means that the influence of this index on SCRE

Commenting on the acceptance of the hypothesis	Degree of membership
Complete acceptance of the hypothesis	1.0
Very high possibility and assurance of accepting the hypothesis	0.9 – 1.0
High possibility of accepting the hypothesis	0.7 – 0.9
Medium possibility of accepting the hypothesis	0.5 – 0.7
Low possibility of accepting the hypothesis	0.0 – 0.5
Rejecting the hypothesis	0.0

Table 3.
Acceptance scale of a hypothesis in the fuzzy environment

Table 4. Statistical analysis of data under fuzzy environment

Category	Index	Commenting on the assumed effectiveness of the index	Acceptance of zero assumption	Acceptance of alternative assumption	Average			Standard deviation
					$\bar{X}_c$	$\bar{X}_b$	$\bar{X}_a$	
Vulnerabilities	1. Turbulence	Medium possibility of accepting the assumption of index effectiveness	0.45	0.55	6.62	4.73	3.08	1.38
	2. Deliberate threats	Rejecting the assumption of index effectiveness	1.00	0.00	5.40	3.48	2.06	1.48
	3. External pressures	Accepting the assumption of index effectiveness	0.00	1.00	7.91	6.64	4.75	1.48
	4. Resource limits	High possibility of accepting the assumption of index effectiveness	0.27	0.73	7.13	5.20	3.22	0.92
	5. Sensitivity	Accepting the assumption of index effectiveness	0.00	1.00	7.82	6.22	4.22	0.91
	6. Connectivity	Accepting the assumption of index effectiveness	0.00	1.00	7.68	6.22	4.26	1.54
	7. Supplier/customer disruptions	Very high possibility of accepting the assumption of index effectiveness	0.09	0.91	7.36	5.43	3.46	1.30

(*continued*)

Table 4.

Category	Index	Commenting on the assumed effectiveness of the index	Acceptance of zero assumption	Acceptance of alternative assumption	Average $\bar{X}_c$	$\bar{X}_b$	$\bar{X}_a$	Standard deviation
Capabilities	8. Flexibility in sourcing	Medium possibility of accepting the assumption of index effectiveness	0.43	0.57	6.82	4.95	3.04	0.82
	9. Flexibility in order fulfillment	High possibility of accepting the assumption of index effectiveness	0.26	0.74	7.02	5.08	3.22	1.35
	10. Capacity	High possibility of accepting the assumption of index effectiveness	0.19	0.81	7.17	5.33	3.33	1.08
	11. Efficiency	High possibility of accepting the assumption of index effectiveness	0.14	0.86	7.37	5.44	3.46	0.98
	12. Visibility	High possibility of accepting the assumption of index effectiveness	0.10	0.90	7.11	5.33	3.42	1.64
	13. Adaptability	High possibility of accepting the assumption of index effectiveness	0.19	0.81	7.20	8.28	3.42	1.18
	14. Anticipation	Weak possibility of accepting the assumption of index effectiveness	0.68	0.32	6.31	4.31	2.46	1.31
	15. Recovery	Accepting the assumption of index effectiveness	0.00	1.00	7.88	6.26	4.33	1.26
	16. Dispersion	High possibility of accepting the assumption of index effectiveness	0.13	0.87	6.91	5.35	3.57	1.48
	17. Collaboration	Weak possibility of accepting the assumption of index effectiveness	0.85	0.15	5.91	3.91	2.17	1.27
	18. Organization	High possibility of accepting the assumption of index effectiveness	0.18	0.82	7.22	5.35	3.37	1.06
	19. Market position	Very high possibility of accepting the assumption of index effectiveness	0.06	0.94	7.46	5.33	3.57	1.6
	20. Security	High possibility of accepting the assumption of index effectiveness	0.30	0.70	7.04	5.11	3.24	1.07
	21. Financial strength	Weak possibility of accepting the assumption of index effectiveness	0.74	0.26	6.06	4.13	2.42	1.46

should be rejected. Conversely, for "external pressure," "sensitivity," and "connectivity," with the membership degree of one, the impact on SCRE should be fully accepted. As far as the "external pressure" index is concerned, this outcome is consonant with Hamel and Valikangas (2003), Pettit *et al.* (2010, 2013), Peck (2005). Similarly, the outcomes obtained for "sensitivity," correspond with Pettit *et al.* (2010), Peck (2005) and Sheffi and Rice (2005); finally, correspondence with Pettit *et al.* (2010), Hamel and Valikangas (2003) and Svensson (2002) can be observed for "connectivity." Moreover, "supplier/customer disruptions" with a membership degree of 0.91 (which highlights the possibility of very high impact) is accepted too; this outcome is consonant with Pettit *et al.* (2010, 2013) and Svensson (2002). The same consideration is true for "resource limitation," which got a membership degree is 0.73 and shows a high potential impact; this index will be accepted and corresponds with Pettit *et al.* (2010, 2013). Similarly, the "turbulence" index with a membership degree of 0.55 is accepted, with an average probability of correspondence with Pettit *et al.* (2010) and Svensson (2002).

(3) Among the enabling indices, for indicators such as "visibility" and "market position" (whose membership degrees are 0.90 and 0.94, respectively) with a very high frequency, the assumption of their impact on SCRE will be accepted. As far as "market position" is concerned, these findings correspond with Hamel and Valikangas (2003), Pettit *et al.* (2010, 2013), while for "visibility" our findings are consonant with Rice and Caniato (2003) and Peck *et al.* (2003).

(4) Indexes like "dispersion," "organization," "adaptability," "capacity," "flexibility in order fulfillment," and "security" got membership degrees ranging from 0.87 to 0.70. Their influence on SCRE is therefore accepted. The outcomes for the "dispersion" capability are consistent with Hamel and Valikangas (2003) and Pettit *et al.* (2010, 2013), while for "efficiency," they show correspondence with Rice and Caniato (2003) and Peck *et al.* (2003). Similarly, correspondence can be found for "organization" (Rice and Caniato, 2003; Pettit *et al.*, 2010, 2013), "adaptability" (Pettit *et al.*, 2010, 2013; Tang, 2006), "flexibility in order fulfillment" and "security" (Hamel and Valikangas, 2003; Pettit *et al.*, 2010; Peck, 2005).

6. Discussion

It is evident from the results of this study that SCRE has a direct impact on the overall supply chain performance. To compete in this challenging environment, supply chain management has been changed from a fragmented chain to an integrated chain. Moreover, due to globalization and digitization and after the introduction of information technology, supply chain activities are becoming more uncertain and vulnerable. Variations in supplier's delivery due to the increasing trend of having global suppliers and frequent customer preference changes made the supply chain riskier. Therefore, organizations need to design their supply chain so as they can predict disruptions or, in case of disasters, minimize their impact on supply chain performance. In line with this premise, in this study, we have analyzed the effect of supply chain capability and vulnerability elements in a specific context, i.e. the Iranian automotive industry. The results obtained show that the automotive industry of Iran should counteract five main elements of vulnerability, i.e. "external pressures," "sensitivity," "connectivity," "supplier/customer disruptions," and "resource limits." A suitable way to counteract "supplier/customer disruptions" could be, for instance, to redesign the purchasing process by distributing the supplies among both 1st tier suppliers and 2nd tier ones. This is also expected to increase the flexibility of automotive industries, making them more prepared in case of any disaster. As far as the resilient capabilities are concerned, the automotive supply chain should enhance "flexibility in order fulfillment," "capacity," "efficiency," "visibility," "adaptability," "recovery," "dispersion," "organization," "market position" and "security" as the most effective countermeasures to vulnerability.

For example, Toyota Motor Corporation faced significant production loss due to the earthquake, tsunami and nuclear meltdown in Japan in 2011. In response, to build a disaster-resilient future, Toyota moved some of its production to other countries to improve flexibility and manage vulnerability in case of future disasters. Vulnerability and flexibility are inter-related concepts. In this respect, we demonstrate the Iranian automotive industry is in a transition phase, from traditional supply chain management to resilient supply chain management, compared to the world-class automotive manufacturing companies. It is noteworthy that by flourishing the capability elements and overcoming the vulnerability factors, the Iranian automotive industry can gradually implement resiliency to cope with disruptive events, even in light of the economic sanctions.

However, more awareness and cultural change are required to adopt and designing resilient supply chains. Similarly, this study demonstrates that collaboration and visibility are also perceived as important for companies to improve their performance and increase the surplus.

6.1 Managerial implications

The outcomes of this research can be of interest to supply chain managers in the automotive industry, in particular those who work in developing countries. First, using fuzzy hypothesis testing allows supply chain managers to identify, intervene and eliminate vulnerabilities and enhance the capabilities of their SCRE. In addition, outsourcing is a viable and practical strategy for mitigating risks and vulnerabilities (i.e. turbulence, deliberate threats) in supply chains. Second, regarding strengthening the capability elements like collaboration and security, supply chain managers should grow their relationship with known suppliers and partners, and reduce ties with unknown and vulnerable partners who could potentially weaken their SCRE. The findings of this research could help supply chain managers in the automotive companies to survive in the highly vulnerable and competitive markets by adopting the following two strategies: (1) regulating their internal resources and taking a resource-based view to reconcile between the vulnerability and capability elements, and (2) using a market-based view to improve their SCRE and efficiently compete with rivals, benchmarking operations and adopting best practices, and ultimately reaching the efficient frontier in the industry.

7. Conclusion and future research directions

7.1 Summary of the contribution

This paper explains the impact of some selected indicators on the resilience of the supply chain. Fuzzy hypothesis tests and the determination of the membership degree were used to evaluate the effectiveness of each index. Flexibility in the supply chain is an important aspect to meet customer demands effectively and efficiently. The modern supply chain should be flexible so that organizations will be able to manage variation in demand in an effective manner. Similarly, visibility is essential for the organization so that the supply chain will be able to predict and manage risk and sustain its effect on supply chain performance. The empirical analysis reveals that indexes like "flexibility in sourcing," "anticipation," "financial strength" and "collaboration" got low membership degrees; therefore, it is suggested that companies in the automotive industry of Tehran strengthen these measures to achieve greater elasticity in the supply chain. On the other hand, since "external pressures," "sensitivity," "connectivity" and "supplier/customer disorders" have a high degree of membership, it is suggested that companies in the auto parts industry reduce the effects of these factors to experience greater resilience in their supply chain by considering appropriate policies. This study explores the capabilities and vulnerabilities of the supply chain in a specific industry field, and, because of its empirical nature, it is expected to represent a stepping-stone in the existing field of knowledge and research in SCRE.

7.2 Future research directions

Based on the analysis of our result and considering the limitations of our study, we propose the following future research ideas:

(1) This study focuses exclusively on the auto parts industry in the Tehran province of Iran. Further research can have the potential of transferring such findings to other industrial sectors such as service, textile, aviation, and oil and gas.

(2) This study can be extended in developing a decision support system based on a fuzzy inference system to identify the effect of different resilience factors on the performance of the whole supply chain.

(3) This study can be useful in developing and proposing a framework for resilience supply chain performance measurement, which evaluates resilient supply chain performance in different industrial sectors.

(4) In addition to the factors that we considered in this study, a more comprehensive list of factors could be obtained through an extensive literature review and by analyzing the effects of these factors' impact on supply chain performance.

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Appendix. Questionnaire

This survey is designed to evaluate supply chain resilience key elements that contain vulnerability and capability factors in your company. Please appraise each factor associated with each group of vulnerabilities and capabilities employing the following five-point scale:

Very low	1
Low	2
Medium	3
High	4
Very high	5

Category	Criteria	Sub-criteria	1	2	3	4	5
Vulnerabilities	1. Turbulence	1.1. Unpredictable demand shifts in products	☐	☐	☐	☐	☐
		1.2. Dependency to supplies and export markets that endure vigorous currency or price fluctuations	☐	☐	☐	☐	☐
		1.3. Facing disruptions because of geopolitical turmoil in imports/exports	☐	☐	☐	☐	☐
		1.4. Natural disasters mostly threaten company's facilities or markets	☐	☐	☐	☐	☐
		1.5. Facing unforeseen technology defeats in the operations	☐	☐	☐	☐	☐

Table A1.
Questionnaire

(*continued*)

Category	Criteria	Sub-criteria	1	2	3	4	5
	2. Deliberate threats	2.1. Facing liability claims in products or operations	☐	☐	☐	☐	☐
		2.2. Possibility of being targeted by terrorism or facility desolation	☐	☐	☐	☐	☐
		2.3. Possibility of industrial espionage of products or technologies	☐	☐	☐	☐	☐
		2.4. Regular vandalization or robbery of the products	☐	☐	☐	☐	☐
	3. External pressures	3.1. Threat of products by repeated competitive innovations	☐	☐	☐	☐	☐
		3.2. Severe price competition of products with rivals	☐	☐	☐	☐	☐
		3.3. Dependency of products to changes of governmental regulations	☐	☐	☐	☐	☐
	4. Resource limits	4.1. Large number of members in company's supply chain	☐	☐	☐	☐	☐
		4.2. Limited capacity of company production as well as suppliers	☐	☐	☐	☐	☐
		4.3. Scarcity of raw materials for the products	☐	☐	☐	☐	☐
		4.4. Difficulty in hiring high-skill and professional workers	☐	☐	☐	☐	☐
	5. Sensitivity	5.1. Co-dependency or geographical concentration of manufacturing facilities	☐	☐	☐	☐	☐
		5.2. Hazardous conditions for workers during operating	☐	☐	☐	☐	☐
		5.3. Strict storage or handling requirements of products	☐	☐	☐	☐	☐
		5.4. Complexity of production operations	☐	☐	☐	☐	☐
	6. Connectivity	6.1. Being part of a universal distributed supply chain	☐	☐	☐	☐	☐
		6.2. Need of particular components for most of products	☐	☐	☐	☐	☐
		6.3. Outsourcing operations to diverse companies	☐	☐	☐	☐	☐
	7. Supplier/ customer disruptions	7.1. Facing remarkable disruptions by suppliers	☐	☐	☐	☐	☐
		7.2. Facing substantial disruptions by customers	☐	☐	☐	☐	☐
Capabilities	8. Flexibility in sourcing	8.1. Instantly changing the inputs of the products or the mode of them	☐	☐	☐	☐	☐
		8.2. Having alternate sources of inputs	☐	☐	☐	☐	☐
		8.3. Flexibility in supply contracts to modify the quantities, terms and specifications of key inputs	☐	☐	☐	☐	☐
	9. Flexibility in order fulfillment	9.1. Swiftly reallocate orders to diverse suppliers or jobs to various production units	☐	☐	☐	☐	☐
		9.2. Having effective inventory management system	☐	☐	☐	☐	☐
		9.3. Quickly shifting the mode of transportation of products and routing the orders	☐	☐	☐	☐	☐
		9.4. Being more responsive to orders by delay in production	☐	☐	☐	☐	☐

(continued)

Table A1.

Category	Criteria	Sub-criteria	1	2	3	4	5
	10. Capacity	10.1. Having dependable back-up utilities (water, electricity, etc.)	☐	☐	☐	☐	☐
		10.2. Marinating access to redundant resources (types of equipment, facilities, etc.)	☐	☐	☐	☐	☐
	11. Efficiency	11.1. High productivity of labors and high-reliability equipment	☐	☐	☐	☐	☐
		11.2. Producing high-quality products with a reasonable amount of waste	☐	☐	☐	☐	☐
		11.3. Effectively utilizing assets and resources	☐	☐	☐	☐	☐
	12. Visibility	12.1. Tracking all operations through an effective information system	☐	☐	☐	☐	☐
		12.2. Regular information interchange among different parties of supply chain	☐	☐	☐	☐	☐
		12.3. Assessing real-time data on the location and status of products, raw materials and other resources	☐	☐	☐	☐	☐
	13. Adaptability	13.1. Developing innovative technologies to foster operations	☐	☐	☐	☐	☐
		13.2. Utilizing continuous improvement programs	☐	☐	☐	☐	☐
		13.3. Being flexible to the changes in market	☐	☐	☐	☐	☐
	14. Anticipation	14.1. Employing efficient demand forecasting methods	☐	☐	☐	☐	☐
		14.2. Rapidly diagnosing warning signals of conceivable disruptions	☐	☐	☐	☐	☐
		14.3. Recognizing and capitalizing on new business ideas to enter the new markets	☐	☐	☐	☐	☐
	15. Recovery	15.1. Having an effectual communication strategy in an emergent situation	☐	☐	☐	☐	☐
		15.2. Mitigate the traces of disruptions taking rapid actions	☐	☐	☐	☐	☐
		15.3. Handling the crises situations successfully	☐	☐	☐	☐	☐
	16. Dispersion	16.1. Distributing production facilities at diverse locations	☐	☐	☐	☐	☐
		16.2. Geographical diversity in customers locations	☐	☐	☐	☐	☐
		16.3. Accessing to a decentralized network of suppliers for providing key inputs of the company	☐	☐	☐	☐	☐
	17. Collaboration	17.1. Exploiting shared data for collaborative demand forecasting	☐	☐	☐	☐	☐
		17.2. Utilizing product life cycle management techniques and programs that are proactive	☐	☐	☐	☐	☐
		17.3. Collaborative decision making among different members of the supply chain through transparent data flow	☐	☐	☐	☐	☐

Table A1. (*continued*)

Category	Criteria	Sub-criteria	1	2	3	4	5
	18. Organization	18.1. Applying creative problem-solving approaches	☐	☐	☐	☐	☐
		18.2. Having employees caring culture	☐	☐	☐	☐	☐
		18.3. Training employees with a wide diversity of skills	☐	☐	☐	☐	☐
	19. Market position	19.1. The loyalty of customers to products of the company	☐	☐	☐	☐	☐
		19.2. Strong communications ways with customers	☐	☐	☐	☐	☐
		19.3. Possibility of entering novel domestic and international markets	☐	☐	☐	☐	☐
		19.4. Superb customer recognition of company's brand	☐	☐	☐	☐	☐
	20. Security	20.1. Providing a high level of security in information systems of the company	☐	☐	☐	☐	☐
		20.2. Training personnel for security programs	☐	☐	☐	☐	☐
		20.3. Collaboration with governmental and expert organizations to improve the cybersecurity defensive systems	☐	☐	☐	☐	☐
	21. Financial strength	21.1. Accessing notable financial reserves to supply potential requirements	☐	☐	☐	☐	☐
		21.2. Diversity of company's business portfolio	☐	☐	☐	☐	☐

Table A1.

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