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SPATIAL COMPLEXITY AND SUSTAINABLE SUPPLY CHAIN PERFORMANCE: THE MEDIATING ROLE OF RESPONSIVENESS IN RESILIENCE AND ROBUSTNESS

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ABSTRACT

Spatial complexity has become a critical structuring situation in modern supply chains, where the word multiplicity, interdependence and degree of coordination is compacted into a single word, spatial configuration supply-chain activities. However, its increased topicality has been accompanied by an act of constant confusion with geographic dispersion in the analysis of empiric materials, thus leaving the structural implication of the supply-chain performance to be under-researched. It follows that the current paper questions the impact of spatial complexity on sustainable supply-chain resilience and robustness as it analyzes the moderating impact of supply-chain responsiveness. The investigation is based on the Resource-Based View and Dynamic Capabilities Theory, and the methodology of the study is deductive and quantitative. The data on surveys was collected among the firms that represent various industries in Saudi Arabia; the number of valid responses was 98. Measures of spatial complexity, resilience, robustness, and responsiveness were measured using adapted measurement scales and the hypothesized relationships were tested using Partial Least Squares Structural Equation Modelling (PLS-SEM). The results of the empirical study show that spatial complexity and supply chain robustness have a strong negative correlation, which suggests that structurally complex supply chains have challenges trying to maintain the performance even in unfavorable conditions. On the other hand, spatial complexity has no direct harmful impact on resilience, but instead, responsiveness completely mediates the relationship between spatial complexity and resilience as a result, the essentialness of adaptive coordination and reconfiguration capabilities of complex spatial arrangement became prominent. There was no emergence of a mediating effect that ensures robustness to support one more differentiation of mechanisms in adaptive recovery and structural stability. By resocializing the concept of spatial complexity as an essential structuring feature, not as a proxy of dispersion this study not only adds to the development of the theory of supply-chain, but it also provides insights on how structurally complex supply chains can be designed.

KEYWORDS: Spatial Complexity; Supply Chain Resilience; Supply Chain Robustness; Supply Chain Responsiveness; Sustainable Supply Chains; Saudi Arabia.

1. INTRODUCTION

The intensity of spatial complexity in supply chain networks has been enhanced due to globalization of corporate operations. Spatial complexity refers to the distribution of suppliers, manufacturing premises, and distribution hubs among various locations and it is usually in different countries or regions (Mishra et al., 2024). Whereas these geographically dispersed structures may have competitive benefits, such as cost-effectiveness, increased market reach, and enhanced flexibility of operation, due to multinational network structures, they also simultaneously form a structural source of supply-chain problems. The high level of spatial complexity burdens the firms with the requirement to coordinate their operations, the growth of uncertainty and the inability to coordinate operations that are in different places. In this context, responsiveness comes out as a key attribute of supply chains with complex geographical configurations. Flexibility is usually described as the ability of a supply chain to react efficiently to the alterations in demand or other environmental factors. Responsiveness, however, when used across geographies can be limited, not accelerated, the communication cycle is longer, there is less synchronization between geographically separated actors, and operational lead time is long, all of which slow down responsiveness speeds and decrease flexibility. Spatial complexity is therefore capable of reducing responsiveness, thus affecting the manifestation of resilience and robustness in supply chains (Richey, 2021). Though the geographic distribution is commonly viewed as an approach to market coverage and minimization of overhead costs, the structural constitution can also be weak that leads to the loss of efficiency and responsiveness. This research thus aims at explaining the role of spatial complexity in responsiveness as one avenue in which resilience and robustness are determined. The results should be used to guide the best practices in sustainable supply-chain design and management by clarifying how organizations that work in locations that are dispersed can improve adaptability as well as competitive advantage.

Over the past years, global pandemics, climate crises, geopolitical disputes, and an increased digital vulnerability have caused a disruption in supply chains like never before. These incidences have revealed the weaknesses in spatially intricate supply chains, especially those that are functioning in a developing economy (Najafi, 2024; Haikal et al., 2023; Parast and Subramanian, 2021). Although spatial complexity may be a useful strategy due to cost-efficiency and the ability to reach a wider market, it also creates more coordination issues, regulatory imbalances, and delays in responsiveness during situations of stress (Holgado & Niess, 2023). In countries that are characterized by large spatial distribution like Saudi Arabia, a variety of regulations, and constant digital change like in Saudi Arabia, the ability of firms to change dynamically is particularly important. According to recent research, the mediating importance of dynamic capabilities is increasing, and organizations should learn to sense upcoming threats, opportunities and restructure their operations in reaction to disruption (Alfarsi and Alshehri, 2024; Jiang et al., 2024; Bag et al., 2019). Responsiveness is becoming an established operational quality which is also a strategic facilitator of resilience and strength in unstable environments (Huo, 2024). These changes support the topicality and topicality of the current study that empirically examines the role of responsiveness in mediating the association between spatial complexity and supply-chain performance in a national setting that is fast changing. Even though there is increasing academic focus, literature is split on the topic of responsiveness in responding to challenges that are spatial complexity. The significance of flexibility in global supply chains has also been confirmed by other studies (Christopher, 2016; Aitken et al., 2005) and the recent research also shows that the role of geographic distribution in supply-chain resilience, reliability, and flexibility has become increasingly important (Slam, 2023). With the ongoing growth of global supply chains, there has been an increased need to state how spatial complexity affects performance outcomes. The aim of the study, thus, is to contribute to the supply-chain management theory and to offer practical contributions to managers who aim at enhancing the supply-chain performance in such contexts that are often marked by disruption and uncertainty. By resolving these problems, organizations are prepared with the ability to develop supply-chain systems that are lean as well as flexible and able to absorb and recover in case of disruptions. Scientifically, this study is important to the development of knowledge on supply-chain management in that it explores how the aspect of spatial complexity affects the resilience, robustness, and responsiveness of supply-chain. To the best of our knowledge, previous studies have focused more on the studies of these constructs in isolation, rather than the joint study of their impacts on the general performance of the supply chain. The supply-chain performance management is all about efficiency, effectiveness, and adaptability as the main pillars of competitive sustainability in any global industry (McAdam and McGlothin, 2002; Gunasekaran et al., 2015). The systematic analysis of the performance implications of spatial complexity may thus provide any useful information to organizations that have to work in more complex and dispersed supply-chain settings. In addition, three unique supply-chain capability models should be distinguished, including reliability-oriented systems capable of maintaining performance in both rose and fall conditions; recovery-oriented systems capable of surviving and recovering when disrupted; and responsiveness-oriented systems capable of improving performance with adaptive change (Tukamuhabwa et al., 2015; Soliman, 2017). The paper aims to avoid overlooking these differences by looking at the interaction of the concept of spatial complexity with robustness, resilience, and responsiveness concurrently. The implications of knowing these interactions are significant to organizations that desire to enhance the reliability, flexibility, and productivity of their supply chains within the changing global environment.

This paper has an empirical concentration on the companies which conduct business in Saudi Arabia, an emerging economy whose geographic and economic characteristics are unique. The industry in Saudi Arabia is spread in the region with vast territories, and the supply-chain networks are exposed to diverse risk in the Middle East region. This background offers a rather appropriate context in which the impact of spatial complexity on supply-chain resilience, responsiveness, and robustness can be studied. The element of robustness as the capacity of a supply chain to remain stable and perform optimally in the circumstances unfavorable to the supply chain is particularly applicable in this environment (Yusuf, 2023). Introducing the concept of robustness in the analysis is thus critical in coming to terms with how the supply chains in Saudi Arabia not only remain undisrupted but also provide sustainable operations within the chain. In addition to theoretical contributions, the results of this study can provoke the creation of new methods of measuring the vulnerability of supply-chain and recovery strategies. Understanding of how the spatial complexity affects the supply-chain performance can be used to develop risk-management models, global supply-chain network models, resilience indices, simulation-based methods, and decision-support systems, which can be used to improve real-time decision-making in a volatile environment (Giannakis and Papadopoulos, 2016; Meixell and Gargeya, 2005; Agarwal, Seth, and Agarwal, 2022; Oberkampf, de Land, Rhett, and Alvin, 20 Previous literature has suggested more detailed assessment frameworks that consider the exposure to risks, as well as protective mechanisms of supply chains (Juttner & Maklan, 2011; Behnam and Ramesh, 2020). Practically speaking, the paper attacks the basic managerial problems that are related to the operation under complex and spatially divided supply-chain environment. The impact of diversification of organizations becomes evident as organizations experience increased operational risks due to disruptions, regulatory differences, as well as, heterogenous economic conditions as organizations diversify geographically. The experience that comes with this study provides operational insights to supply-chain managers who need to improve the resilience and reliability. Placing responsiveness as an agent of solving spatial complexity, the study offers practical measures to enhance communication, coordination, and collaboration of supply-chain networks (Emrouznejad, 2023). Organizational responsiveness and the speed of response can also be enhanced by investing in advanced technologies that ensure real-time monitoring and analytics (Asamoah et 2021). Finally, the results indicate the practical applicability of enhancing both strength and flexibility, which can help organizations survive shocks and take advantage of opportunities in an ever-uncertain global business climate.

1.1. Research Aims

The main objective of this research is to question how the spatial complexity has an impact on the resilience and robustness of a supply chain, and at the same time assess whether the responsiveness of the supply chains is a better explanation of how the effects on supply chains come to pass. The research clearly aims at establishing a direct constraining influence of spatial complexity on the ability of a supply chain to maintain a steady performance and to bounce back after a disruption or whether these possibilities are conditional on the level of responsiveness entrenched in the supply-chain design.

The study aims at clarifying the similar or divergent effects of spatial complexity on the same performance dimensions by putting in a strict distinction between resilience and robustness. Further, the study identifies responsiveness as a mediating performance of whether it diminishes or enhances the impact of spatial complexity on supply-chain performance. The aim of this methodological approach is to provide an empirically testable structured and empirically testable description of the spatial complexity in its influence on supply-chain performance under circumstances of uncertainty.

To achieve the general goal, the study has outlined the following specific sub-objectives in each corresponding to the proposed hypotheses:

- To investigate the direct influence of spatial complexity on supply chain resilience.
- To test the immediate impact of spatial complexity on robustness of supply chain.
- To determine how the spatial complexity influences the response of the supply chains.
- To measure the mediating effect of supply chain responsiveness in the connection between spatial complexity and supply chain resilience.
- To test the hypothesis of whether supply chain responsiveness mediates the spatial complexity-supply chain robustness relationship.

1.2. Research Question

The acceleration of structural complexity in supply chains highlights basic questions about how spatially complex structures influence the performance of supply-chain in the context of disruption and uncertainty. Spatial complexity is often discussed in connection with strategic benefits, yet the relationship between it and resilience and robustness has not been a theoretically blurry and empirically inadequate topic. More specifically, it remains unclear whether spatial complexity has a direct negative impact on supply-chain performance, or the impact is mediated by adaptive responsiveness of an organization.

In its turn, the main research question that leads to this study is the following:

What are the impacts of spatial complexity on supply chain resilience and robustness and how does the responsiveness of supply chains mediate these effects?

The question is answered by the investigation of the following interrelated sub-questions that represent the structural and capability-based mechanisms underlying the supply-chain performance:

- What is the relationship between spatial complexity and supply chain resilience?
- What is the spatial complexity in terms of supply chain robustness?
- What is the effect of spatial complexity on supply chain responsiveness?
- Does supply chain responsiveness interpose the connection between spatial complexity and supply chain resilience?
- Is supply chain responsiveness the mediator of the correlation between spatial complexity and supply chain robustness?

All these questions put together define a comprehensive inquiry on the differentiated performance implication of spatial complexity. The analysis of resilience and robustness in parallel and the articulation of the mediating role of responsiveness will enable the study to overcome the divisive approaches and in so doing, provide a consistent theoretical exposition of the operation and performance of structurally complex supply chains under modern business conditions.

1.3. Research Contribution

This research brings in several relevant findings to the theoretical and empirical discussion on the topic of supply chain management. First, it conceptualizes spatial complexity by transforming it into a structural determinant giving rise to differentiated performance results, as opposed to simplifying it as an oversimplified proxy of geographic dispersion. Through an empirical inquiry of both the resilience and the robustness through a common analytical platform, the research responds to the earlier calls of a greater conceptual clarity in respect to the supply chain performance capabilities, and the various functions involved in the capability and its discrete functions during a state of disruption. Secondly, the study also contributes to the theory by a direct discussion of the mediating role of responsiveness, thus clarifying how spatial complexity determines supply chain performance. Such distinction will show that the impact of spatial complexity on resilience and robustness is not uniform and that dynamic capabilities can counterbalance some structural disadvantages and leave some unaddressed. Thirdly, the empirical concentration of the study on the Kingdom of Saudi Arabia supplements the limited extant body of literature on supply chain practices in emerging economies. The lessons learned shed light on the way supply chains of a spatially complex nature work in an environment of regulatory heterogeneity, infrastructural difference, and increased exposure to disruption, and thus broadens the extrapolative applicability of existing theories about supply chains.

1.4. Structure of the Paper

The rest of this manuscript is structured in the following way. Section 2/20 reviews the relevant literature and creates the theoretical background of the spatial complexity, supply chain resilience, robustness, and responsiveness. Section 3 outlines the conceptual framework and formulates the research hypotheses. Section 4 gives the methodology, including data gathering, measurement construction, and methods. In section 5, the empirical findings have been provided. Section 6 provides the discussion of the results, outlines theoretical and managerial implications, and defines the study limitations and future research direction.

2. THEORETICAL BACKGROUND

2.1. Spatial Complexity

The process of systematic distribution of various supply-chain operations at a variety of geographical locations is known as supply chain spatial complexity (Ojha et al., 2018). Its modern applicability is due to the increased operational efficiency sought by the organizations, the perception of specific target customer groups, and the alleviation of varied risk exposures. Several advantages relate to the geographical diversification of operations: companies are hoping to achieve economies of scale, maximize the use of resources, and expand market scope (Chor & Alfaro, 2023). One of the most evident challenges posed by the supply-chain management is the impossibility to coordinate the supply and demand at a very large scale, and the problem is aggravated by the disparity in regulatory environments of different countries and regional threats like natural disasters and political conflicts. To illustrate, the escalation of trade conflicts between the United States and China triggered many organizations to redesign their supply-chain approaches and ceased the existence of global networks, moving instead to nearshoring. This shift created a preference towards proximate bases of production and countries like Vietnam and Mexico became salient substitutes. Therefore, nearshoring has been popularized within many companies to mitigate the exposure to risks as opposed to the traditional globalization (Alfaro & Chor, 2023; Saisridhar, 2023).

Nearshoring has some discouraging factors such as high cost of production, lack of local experience, and the risks of localization which offset the opportunities of nearshoring. On the other hand, nearshoring has certain advantages such as low operational costs, availability of regional expertise and local market access thus it can be said to have better advantages compared to the traditional globalization advantages that include economies of scale and access to more markets. Geographic diversification of a supply chain can make it stronger through the dispersal of supply. Such spatial dispersion reduces any form of reliance on a given region, thus reducing the chances of impairments caused by the locally specific events like natural calamities, political instability, or any regional problem. A good example of this dynamic is the intricate, multi-national chain of supply-chain of Apple that cuts across various countries across the globe and as a result of this diversification, it can leverage different forms of advantage, especially the labor availability and technological infrastructure. However, the impact of disruptions on important segments, such as the semiconductor shortage caused by the COVID-19 pandemic, required Apple to seek alternative sources of manufacturing, such as India (Saisridhar, 2023).

2.2. Supply Chain Resilience

The concept of supply chain resilience implies the ability of supply-chain networks to predict, reduce, respond, and adjust to the disruptions that could occur when the chain is functioning, including natural disasters, political instability, or changes in the economic environment (Tukamuhabwa et al., 2015; Soliman, 2017). The business continuity management is a proven remedy that helps an organization remain functional and reduce negative effects of such incidents on the customers and operational aspects. On the other hand, operational supply-chain robustness refers to the capability of supply chain to perform best in unfavorable situations through management strategies like redundancy and advanced inventory management methods. The exploration of the reasons why such phenomena occur and the clarification of the connection between resilience and robustness is one of the main issues of businesses in the global environment (Mackay et al., 2020; Zhang and Mohammad, 2024; Sulaiman et al., 2020). Various theoretical frameworks shed light on different things about resilience. One such theory is the Resource Based View; companies that possess internal capabilities that are valuable, rare, inimitable, and non-substitutable can absorb shocks faster; they also recuperate faster. In line with this, investment in flexible processes of manufacture, well-developed information-technology infrastructure, and a highly skilled workforce are some of the major levers to increasing the resilience. The Dynamic Capabilities Perspective is the expansion of this perspective, which states that valuable resources are not enough, but they must be reorganized and adjusted to new conditions. Dynamic adaptability necessitates perceiving new risks and possibilities, acquiring beneficial locations, and restructuring operations to remain effective in an interfered environment. These are internal and firm-based factors that, therefore, play a central role in building a strong foundation (Rincon and Sarache, 2024; Atieh et al., 2024; Odulaja et al., 2023; Dai et al., 2024). Despite the large amount of literature that has investigated the role of engineering resilience and adaptation, there are limited studies that view resilience as a transformational process. New disruptions are becoming more social-ecological and require new ways of containment (Visnic et al., 2024). The related construct is supply-chain robustness, which has different agendas compared to resilience as it focuses on stable performance amidst fluctuation especially in the face of risk and geographic variability. Although resilience deals with how a supply chain can rebound after a disruption, robustness deals with how an operational efficiency of a supply chain can be maintained when it gets disrupted and it is resistant to disruption that can bring change. Additionally, the resilience of the supply chain is more important regarding the risks associated with the functioning and stability during unstable situations. According to Shishodia et al. (2023), robustness is the ability of the supply-chain networks to sustain risks and pressure without causing a substantial performance reduction. This is unlike resilience which deals with the aspect of restoring order following disruption. The systems should be built in such a way that they are not prone to collapse, especially in cases where the individual parts are spread in varied sites. The existence of spatial complexity adds more risks, including intermittent regulation requirements, infrastructural heterogeneity, and diverse physical environments which make robustness an interesting design dimension to supply chains.

The effect of spatial complexity on resiliency of supply-chain is now more evident. Possible disruption sources are geographic factors such as distances between supply-chain nodes and variability of characteristics between regions. It has also been concluded that geographically decentralized supply-chain operations are susceptible to failure because an issue that occurs at one location can spread into the system. To overcome these risks, companies need effective strategies, including the involvement of different suppliers, the expansion of real-time data processing, and the improvement of supply delivery to maintain the performance (Munim et al., 2023; Ambulkar et al., 2015).

Examples of supply-chain resilience can be provided by such multinational corporations like Apple and Toyota that have several levels of suppliers and guarantee their regular functionality. These organizations structure their supply chains in a way that they do not lose functionality in the event of disruptions hence congruence between the goal of robustness and sustainability. An example of this is the nurturing of partnerships with various major suppliers of key components by Apple to protect operations in the event of disruption caused by suppliers. The lean production system at Toyota underlines that the concepts of resilience reduce wastes and strengthens production process through the application of robustness principles (Sharma et al., 2023). Supply-chain reliability as a concept has gained recent academic attention especially in the face of disruptions like the COVID-19 that revealed weaknesses in geographically separated networks. To evaluate the resilience of supply-chain in such situations, fuzzy decision-making models such as Fuzzy TOPSIS and Fuzzy CRITIC have been applied. These models consider the resilience of firms against disruptions as they are based on the level of exposure to geographic and operational risks (Rajesh et al., 2021).

2.3. Supply Chain Responsiveness

Responsiveness is used in supply-chain systems to refer to the ability of supply networks to make fast and effective changes due to demands, supply, and other market circumstances. It is a decisive factor of the sustainability of a company in unstable situations especially in the current world of global markets where the rapid and efficient response is crucial. Responsiveness is the capacity of supply-chain actors to change the supply-chain activities based on consumer demands, supplier dynamics, or other unpredictable situations; this has become vital to the supply-chain performance (Gunasekaran et al., 2015). Direct influence of spatial complexity on responsiveness is present. On the one hand, dispersed supply chain can face coordination challenge in various regions, thus hindering the decision-making and change implementation. The skill to act fast to emerging trends may be limited by coordination between or among numerous offices with different jurisdictions and different time zones. As an example, companies that are based on different continents can have some serious difficulties in aligning inventory, logistics, and communications on remote markets, and making the entire operation less responsive (Christopher and Peck, 2020). In its turn, geographically spread supply chain can also take advantage of the larger network of suppliers and access to the market, and in most cases is more flexible in switching suppliers and markets in the event of disruption. A dispersed system has the potential in the fact that, in a dispersed system there are numerous nodes in different positions, and this results in rerouting and sourcing of materials whenever a specific area is negatively impacted (Lorentz et al., 2012). Another positive correlation is that between responsiveness and resilience as well as robustness and these have been established to be statistically significant. In contrast to resilience, which concentrates on recovering after disruptions, responsiveness is relevant to make sure that the supply chain can respond appropriately to prevent or reduce the severity of disruption. In this respect, responsiveness can make supply chains more resilient by allowing them to be prepared in advance to the change before it takes place (Gligor et al., 2020). Besides, responsiveness may affect the aspect of robustness, which is the ability of the system to work effectively in different conditions. It can be better maintained through the capability to reassign resources, or change the production processes, more quickly in response to disruptions; that is, it goes into supply-chain responsiveness, as well as cushioning the losses of geographic dispersion (Seifzadeh, 2017; Lynch, 2016; Aming'a et al., 2024).

The two frameworks that this study is theoretically rooted are the Resource-Based View (RBV) and the Dynamic Capabilities View (DCV). In terms of the RBV, resilience and robustness are desirable and hard-to-replicate organizational resources with the capacity to sustain or reestablish operations in supply chains in response to disruptions (Pettit et al., 2013; Barney, 1991). Nevertheless, the RBV can provide little information on how firms react to change. Based on this, we use the DCV in the explanation of responsiveness as a higher-order facility that enables supply chains to detect, grasp, and restructure resources to react to the uncertainty that is geographically dispersed (Teece, 2007). In this, a mediating role should be played by responsiveness between spatial complexity and supply-chain performance, operationalizing the adaptive capacity theorized in the DCV (Gligor et al., 2016). This two-theory basis is what informs the conceptual framework and forms the basis of the hypotheses in the study connecting structure, capability, and performance.

3. CONCEPTUAL MODEL AND RESEARCH HYPOTHESES

3.1. Relationship between Spatial Complexity and Supply Chain Resilience

Spatial complexity, which implies the strategic location of the supply chain activity in non-homogenous geographic locations, may introduce inherent weaknesses in the response to the occurrence of unanticipated challenges. Although this kind of dispersion can be beneficial, such as access to specialized labor pools, lower production costs, and closeness to emerging markets (Chor and Alfaro, 2023), it also increases the complexity of supply chain management. The existing literature has mainly discussed the disadvantageous nature of dispersion that do exist, including the increased managerial complexity of organizing activities in different locations, time zones, and different cultural backgrounds.

The existence of regulatory heterogeneity between regions implies that they must comply with numerous legal authorities, which makes their resources in terms of managers even more strained. Supply chains that are geographically spread are characterized by significantly greater exposure to local risks and include natural disasters, political instability, trade conflicts, policy changes, and structural gaps (Alfaro & Chor, 2023; Saisridhar, 2023). All these aspects have the potential to severely reduce the ability of a supply chain to absorb shocks, adjust rapidly, and quickly recover effectively following disruptions, and therefore reduce resiliency overall. Though the theoretical basis would indicate that the diversification of the location of suppliers may be more adaptable to resilience due to the fact that it decreases the reliance on unique sources, the practical experience, including the example of Apple, does show that the additional complexity and challenges of keeping the process of coordinating actions flowing would often nullify those possible benefits. **This conflict between the advantages of diversification and increased risks of dispersion forms the basis of the following hypothesis:**

H1: The spatial complexity has a negative impact on the supply chain resilience.

3.2. Relationship between spatial complexity and Supply Chain Robustness

The adverse impacts of the spatial complexity might at the same time cause a negative effect on the soundness of the supply chains. This is the definition of robustness, which is not the same as resilience, it is the ability to maintain performance under changing or disadvantageous factors, absorbing the imposed variability, which causes the overall performance to be affected by pressure (Shishodia et al., 2023). The literature describes the geographically dispersed supply chains as being inherently more variable and inconsistent. They often have different regulatory regimes that can be inconsistent and require certain modification, thus increasing the cost of compliance. Inconsistency of infrastructure between sites can develop logistical bottlenecks, delays, as well as increased transportation costs. Additionally, various physical settings present unique risks of climate, natural resources, and local infrastructures, with the possibility of undermining the efficiency and reliability of production (Munim et al., 2023). These natural vulnerabilities, which are part and parcel of the nature of the geographically spread operations, compromise the ability of the supply chain to ensure the consistency of the performance. On this line of reasoning the following hypothesis is conceived:

H2: The spatial complexity has a negative impact on the robustness of supply chain.

3.3. The Mediating Role of Responsiveness: Spatial complexity, Resilience, and Responsiveness

According to Gunasekaran et al. (2015), the supply-chain responsiveness is the ability to react to the modified demand and supply conditions, or sudden market changes effectively and timely. Supply-chain responsiveness mediates the relationship between the spatial complexity and resilience. Though natural barriers to resilience are generated by spatial complexity, a highly responsive supply chain can effectively counteract such negative impacts. A responsive system has the nimbleness to respond in anticipation and to make the adjustments needed to counter the dispersion, like the quicker channeling of materials through other avenues or switching to other suppliers, and to respond adjustments in internal processes with more urgency. Supply chain responsiveness can also help improve the understanding, anticipation, and response to altered conditions in ways that can reduce most of the impacts of dispersion on resilience. In this regard, a responsive supply chain should find it easier to leverage its agility to address coordination issues, adjust to regulatory differences, and reduce risks that are specific to a particular area. The responsiveness improves the readiness of a supply chain to a disruption and its successful restoration (Gligor et al., 2020). The theoretical foundation that this offer is a basis of the following hypothesis.

H3: Responsiveness is a positive mediating variable between spatial complexity and supply chain resilience.

3.4. The Mediating Role of Responsiveness: Spatial Complexity, Robustness, and Responsiveness

These responsive supply chains have gained the ability to become more flexible and agile in operations in case of possible changes. The capacity is reflected in the versatile distribution of resources, fast production response, and dynamic logistical responses whereby responsiveness significantly increases the capacity of the supply chain to withstand pressures, accept variability, and maintain performance in different operational conditions (Gligor et al., 2020). The ability to adjust quickly to changing regulatory conditions, infrastructure limitations, and local incidence disruptions is central to the maintenance of organizational resiliency at the spatially dynamic environment. The relationship between dispersion, robustness and responsiveness is dynamic and the hypothesis can be presented as follows:

H4: The relationship between spatial complexity and supply chain robustness is mediated by responsiveness positively.

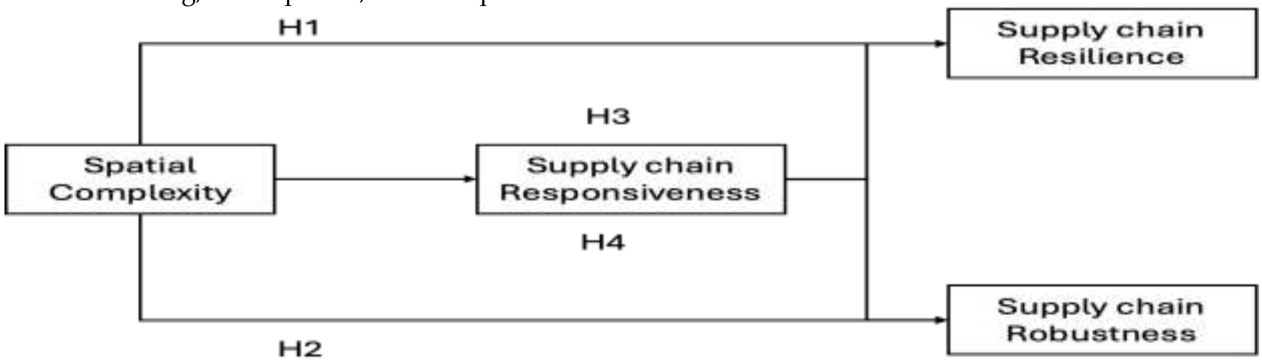

Figure 1 Research model.

Figure 1 illustrates the proposed research model and the hypothesized relationships among spatial complexity, responsiveness, resilience, and robustness.

4. METHODOLOGY

4.1. Research Approach

In this research, a quantitative deductive method was used, which allowed the empirical validation of existing theories regarding supply chain resilience and robustness, that is, in the context of spatial complexity and responsiveness. This was a methodological position in which the numerical data was systematically collected and analyzed in a way that it tested the inter-variable relationships, using the Borgstede variables (Borgstede, 2021).

4.2. Data Collection

The statistics used in this study were collected by the means of a structured questionnaire to the Saudi Arabian workers. The survey tool was carefully designed to ensure that it obtains detailed information about spatial complexity, supply chain resilience, robustness, and responsiveness of different sectors in the industry.

In order to get a representative sample that would cover a variety of industries, the survey was carried among the employees of eleven major industry segments, i.e. Consumer Goods, Food and Beverages, Banking sector, Hospitality and Consulting, Consumer Electronics, Pharmaceuticals, Energy and Utility sector, Shipping and Logistics, Apparel and Textile sector and the Automotive industry. The questionnaire was distributed via the web, and invitations to participate in it were sent in November 2024.

A total of 98 responses were obtained in the survey, which is 25% response rate. Such degree of involvement is agreeable and should contribute to the increased credibility of the dataset and reducing the possibility of response bias. The sample size had an equalized composition of the firms in terms of size: Large Enterprises (≥250 employees), Medium Enterprises (50 to 249 employees), Small Enterprises (10 to 49 employees), and Micro Enterprises (1 to 9 employees) providing a balanced representation of the business environment in the Kingdom and enhancing the extrapolation of the results to a wider group of organizations in Saudi Arabia. The sample size (n = 98) is justified in terms of the use of the Partial Least Squares Structural Equation Modeling (PLS-SEM), which is best applied to the exploratory study of emerging markets and can work with smaller samples, specifically in theory -development situations (Hair et al., 2021). Since five paths are included in the structural model, the most popular rule is the so-called 10 times rule which states that the required number of observations is at least 50 which is exceeded in our study. In addition, the power requirements as stated by Cohen (1992) indicate that the sample size of 65 is sufficient to observe medium effect sizes with 80 percent power at 5 percent significance level, which also supports the sufficiency of the sample.

The survey respondent's demographic and organizational profile in terms of sector, size of the firm, and position of the manager will be given in Table 1 below.

Table 1: Research Sample Profile.

Sector	Sector (%)	Firm Size	Firm Size (%)	Respondent Position	Position (%)
Pharmaceuticals	13.0	Large Enterprise (250 or more Employees)	34.3	Assistant Manager	24.1
Shipping and Logistics	11.1	Medium Enterprise (50 - 249 Employees)	21.3	Manager/Senior Manager	22.2
Banking, Hospitality and Consulting	8.3	Small Enterprise (10 - 49 Employees)	25.9	Director	20.4
Consumer Electronics	8.3	Micro Enterprise (1 - 9 Employees)	18.5	General Manager	16.7
Energy and Utility	8.3			Owner/CEO	16.7
Automotive	8.3				
Food and Beverages	6.5				
Apparel and Textile	6.5				
Consumer Goods	4.6				
Construction	4.6				
Other	20.4				

4.3. Measures

To reflect the complex interactions of spatial complexity, resilience, responsiveness and robustness in the supply chains, the existing scales and measurement tools were modified and integrated into the present study. The supply chain resilience was measured applying the methodology of Pettit et al. (2013) as well as adjusting the tool by taking into consideration the challenges that firms faced during the COVID-19 pandemic. The scale reworded is written in a five-point Likert scale where completely disagree and completely agree were used as anchoring terms, thus, measures the resilience of firms in the face of unpreceded disruption. To determine the strategic importance of the responsiveness of supply-chain, elements introduced by Christopher and Peck (2004) were used, with special reference to strategic priorities related to the primary product line of a firm. It is also an instrument that makes use of a five-point Likert scale, with the most important values being not important at all, moderately important, and extremely important, thus reflecting the level of responsiveness that is sought in the greater supply-chain strategy. This construct was applied to the subjects to determine the effect of external shocks on the subjects with the approaches of Hendricks and Singhal (2005) inspiring such an approach. The respondents evaluated the impact of such events in more than one dimension, i.e., turnover, efficiency, delivery times, cost of procurement, and number of units affected and the well-being of the workers. The broad range of disruption outcomes was taken into consideration using a five-point scale that ranged between a very large negative impact and a very large positive impact.

Following the approach of Craighead et al. (2007), spatial complexity could be measured as the Percentage Distribution of Purchases, Capacity, and Sales across products for eight key geographic region markets. This approach aptly captures the wide view from a company on geographic footprint but can also show the depth of impact on supply chains in terms of resilience-robustness. The specific calculation of dispersion measures for sales, production, and purchasing followed the formula outlined by Lee and Billington (2001):

$$DISP = 1 - \frac{\sum_{i=1}^{n} \left| G_i - \frac{100}{n} \right|}{200\left(1 - \frac{1}{n}\right)} \quad (1)$$

The given formula provides the dispersion measure whose range is between 0 and 1, a value of 0 represents total concentration in one location, and a value of 1 represents even distribution across all locations under analysis.

In order to strengthen the analysis, the logistics outsourcing measures were also included with the help of the methodology developed by Ellram and Tate (2004). By responding to questions concerning the level of outsourcing a variety of logistics operations to an external company on a five-point Likert scale, the respondents have been able to capture the level of reliance of the company on other firms to supply-chain critical functions. Lastly, the possibility of the firm size and the industrial sphere where the supplies are acquired affecting supply-chain settings was recognized, and control variables were a part of the presentation. The size of firms was divided into the reported annual turnover and industry was identified by the dummy variables of the different industries appropriately coded based on industries. The controls allow the study to capture the possible differences in the relations of the main constructs between the firms of various sizes and industries. It is the combination of such different measures and scaling procedures that the study is expected to exhaustively capture the interrelationships of complexity of space, supply-chain resilience, responsiveness, and robustness, especially concerning how external shocks and disruptions affect the supply-chain.

The constructs, measurement items, sources, and types of scales as well as measurement models are summarized in Table 2 below.

Table 2: Constructs Summary.

Construct	Items	Source(s)	Scale Type	Measurement Model
Spatial Complexity	SC1, SC2, SC3	Craighead et al. (2007) Lee and Billington (2001)	5-point Likert	Reflective
Responsiveness	RESP1, RESP2, RESP3	Christopher and Peck (2004)	5-point Likert	Reflective
Resilience	RES1, RES2, RES3	Pettit et al. (2013)	5-point Likert	Reflective
Robustness	RBST1, RBST2, RBST3	Ellram and Tate (2004)	5-point Likert	Reflective

In order to reduce the possible impact of common method bias (CMB) and to enhance the internal validity of the findings, the survey design and administration used a number of procedural safeguards. Anonymity and confidentiality of respondents were also emphasized in order to mitigate the effects of social desirability bias and the survey was conducted as a self-administered online questionnaire in order to reduce the effects of the interviewer. Moreover, the measurement items were obtained out of earlier, peer-reviewed and validated tools, which minimized the conceptual ambiguity and measurement error (Podsakoff et al., 2003). Even though no statistical tests were conducted in this research, the use of theoretically based constructs and homogenous scale format is used to limit the potential of exaggerated correlations due to common method variance. More powerful studies can be conducted in the future by combining both procedural and statistical controls of CMB.

4.4. Model

To test the hypotheses, a regression analysis was employed with the following specifications. We estimated the standard errors of regression coefficients by using a heteroscedasticity-consistent standard error estimator-HC3-following Long and Ervin, 2000-that is suitable for heteroscedasticity, which we suspected to be present in this model. To test H1-H3, which examine the direct effects of spatial complexity, we established the following formulation:

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$Y = \beta_0 + \beta_1 Size + \Sigma_{i=1}{}^4\ \gamma_i Ind_i + \beta_2 SC + \varepsilon$ (2)

where Y = {RESP, RE, RO} represents the dependent variable (supply chain responsiveness, resilience, or robustness, respectively), β_0 is the intercept, and coefficient β_1 indicates the influence of Size. Ind_i is a dummy variable for industry i and γ_i is its coefficient. The analysis compared companies across eleven sectors: Consumer Goods, Food and Beverages, Banking, Hospitality and Consulting, Consumer Electronics, Pharmaceuticals, Energy and Utility, Shipping and Logistics, Apparel and Textile, Automotive, and Construction, with "other industries" serving as the reference category to avoid multicollinearity. β_2 represents the influence of spatial complexity (SC), and ε denotes the error term.

For testing H4 and H5, which examine the impact of Supply Chain Responsiveness on Resilience and Robustness, we developed the following formulation:

$Y = \beta_0 + \beta_1 Size + \Sigma_{i=1}{}^4\ \gamma_i Ind_i + \beta_2 RESP + \varepsilon$ (3)

where Y = {RE, RO} represents the dependent variable (supply chain resilience or robustness), β_0 is the intercept, and coefficient β_1 indicates the influence of Size. As before, Ind_i is a dummy variable for industry i and γ_i is its coefficient, with "other industries" as the reference category. β_2 represents the influence of supply chain responsiveness (RESP), and ε denotes the error term.

5. RESULTS

The PLS algorithm was run with weighting metric scheme settings, 300 maximum iterations and the initial weight of 1.0. In addition, the bootstrapping algorithm was run with cases equal to 98, 5000 samples and no sign changes option. Table 3 presents the AVE, composite reliability, and loading values for all constructs.

Table 3: The Research Variables and Constructs.

Research construct	Description and references	AVE/CR loading
Spatial Complexity (SC)		0.511/0.744
SC1	Our company relies more on production sources from diverse geographic regions than on production concentrated in one geographic region	0.792
SC2	A large portion of our company's direct purchases come from suppliers located in diverse geographic regions rather than from suppliers concentrated in one geographic region	0.739
SC3	A large portion of our company's resources (including sales, production, and purchases) are distributed across multiple geographic regions rather than concentrated in one geographic region	0.710
Supply Chain Resilience (RE)		0.555/0.713
RES1	We are able to adequately respond to unexpected disruptions by quickly restoring our product flow	0.702
RES2	We are well prepared to deal with the financial outcome of potential supply chain disruptions	0.768
RES3	We are able to provide a quick response to a supply chain disruption	0.723
Supply Chain Responsiveness (Respon)		0.591/0.741
RESP1	Enhancing supply security	0.726
RESP2	Maintaining safety inventory of work-in-progress or finished products	0.764
RESP3	Retain excess capacity in manufacturing	0.733
Supply Chain Robustness (Robust)		0.542/0.711

RBST1	Our supply chain and logistics networks can remain effective and be sustained even when internal/external disruptions occur	0.713
RBST2	Our supply chain and logistics networks can avoid or minimize risk occurrences by anticipating and preparing for them	0.767
RBST3	Our supply chain and logistics networks can absorb a significant level of negative impacts from recurrent risks	0.701

Convergent validity, reliability, and internal consistency were evaluated by examining average variance extracted (AVE) and composite reliability (CR) values (Table 1). All of the constructs show an acceptable level of validity and reliability results. Discriminate validity is verified when the square root of the AVE is larger than the correlation coefficients (Fornell and Larcker, 1981). As shown in table 4 below, the discriminate validity in this research is confirmed. In addition, all the constructs outer loading were well above the critical value of 0.5.

Table 4: Discriminate Validity.

	GD	RES	RESP	RBST
GD	**0.707**			
RES	-0.133	**0.745**		
RESP	-0.271	0.435	**0.769**	
RBST	-0.390	0.207	0.124	**0.736**

Before testing the research hypotheses, variance influence factor (VIF) was used to assess the multicollinearity among the predictor constructs. As shown in table 5, VIF values demonstrates that multicollinearity is not an issue in this research (Hair et al., 2017).

Table 5: Multicollinearity Assessment.

	RES	RBST
GD	1.079	1.000
RESP	1.079	1.062

Table 4 presents the results of our regression analyses testing the research hypotheses. The impact of g spatial complexity on supply chain resilience (β = 0.016, p > 0.05) was negative but not statistically significant, providing no support for H1. Spatial complexity showed stronger effects on supply chain robustness (β = -0.385, p < 0.05), supporting H2. Supply Chain responsiveness demonstrated a significant positive effect on resilience (β = 0.41, p < 0.05) but its impact on robustness was negligible (β = 0.19, p > 0.05). As a result, H3 is accepted as supply chain responsiveness is fully mediate the relationships between spatial complexity and supply chain resilience. On the other hand, H4 is rejected as supply chain responsiveness has no mediation effect between spatial complexity and supply chain robustness. The F-statistics further confirmed these relationships, with the strongest effect observed for responsiveness on resilience (F = 0.22).

Table 6: Results of Regression Analyses.

Path	B (p)	F		
		RES	RESP	RBST
GD -> RES	-0.016 (0.839)	0.004		
GD-> RESP	-0.271 (0.018)		0.102	
GD -> RBST	-0.385 (0.000)			0.162
RESP -> RES	0.431(0.000)	0.212		
RESP -> RBST	0.019 (0.860)			0.001
Adj R^2		0.173	0.064	0.135
R^2		0.190	0.073	0.152

Table 6 presents the results of the regression analyses testing the hypothesized relationships among spatial complexity, responsiveness, resilience, and robustness. The model explained 19.0% of the variance in supply chain resilience (R^2 = 0.190), 15% in supply chain robustness (R^2 = 0.152), and 7.3% in supply chain responsiveness (R^2 = 0.073). These moderate R-squared values suggest that while our model captures important determinants of supply chain capabilities, other factors not included in our study may also play significant roles in explaining these outcomes.

6. DISCUSSION AND CONCLUSIONS

6.1. Theoretical Implications

The current research also contributes to the development of the supply chain theory by explaining the complex interconnections of spatial complexity, resiliency, robustness, and responsiveness, and more so, the medial role played by the responsiveness (Demirbag & Glaister, 2010). By integrating these constructs into a combined analytic model, its findings go beyond the past studies that have studied them separately and thus provide a more detailed insight into the impact of structural features on the performance of the supply chain (Neimark and Vermeylen, 2016). This way, the study meets the growing need to adopt integrative views that can characterize the multidimensional nature of supply chains in the present times. One of the key theoretical contributions of the study is the definition of the notion of responsiveness as a buffer effect to the issues of spatial complexity, especially in the environment of the developing economy. Whilst it can be merely that the spatial complexity allows gaining strategic benefits, i.e., access to a wide range of resources and markets, the practical outcomes demonstrate that it also imposes significant coordination costs, exposes a firm to local risks, and disrupts information flows (Choi, 2017; Hoskisson et al., 2012; Xu and Meyer, 2012). The study contributes to existing theory by clearly modeling responsiveness as an intervening ability and therefore explaining how companies can ameliorate partially the negative structural effects on spatial complexity.

The study also contributes to the resilience literature by emphasizing that the supply chain performance is also affected by structural and contextual factors in which the supply chain functions (Belderbos et al., 2013). The results support the idea of resilience being a continuously changing phenomenon that is constantly reconfigured in the context of shifting strategic decisions and configuration of capacity under the influence of spatial complexity. Through the simultaneous exploration of resilience and robustness, the research provides a more comprehensive view on supply chain performance, as it shows that companies need to do not just survive the disruption but maintain the stable performance in the case of sustained disruptions. This difference is particularly relevant to the context of the modern globalized and unstable world, in which the supply chains must face a constant and complex set of risks (Zahra et al., 2014; Liu and Vrontis, 2017; Jacob et al., 2013; Singh, 2024; Brito, 2022). More importantly, the empirical results prove the existence of a strong negative direct relationship between spatial complexity and supply chain robustness hence proving the thesis that structurally complex supply chains are more prone to disruption. This finding is consistent with the other studies that associate geographic dispersion with the increased complexity in operations, delays in communication, and the cost of coordination that undermine the stable performance (Durach et al., 2015; Pettit et al., 2013). In comparison, the non-existence of a direct impact on resilience suggests that the capability of recovery should not be solely defined by the structure. The full mediation of responsiveness in spatial complexity resilience relationship underlines responsiveness as a dynamic ability that enables firms to transform structural complexity into adaptive strength in quick decision-making and reconfiguring operations. On the other hand, the lack of mediating role between responsiveness and robustness proves the theoretical boundary between agility-based capabilities and structural stability. Robustness is based on design choices, including redundancy, buffer space, and modular structures, which cannot be substituted by responsiveness (Holcomb and Ponomarov, 2009; Scholten et al., 2014). This distinction supports the view that resilience, robustness, and responsiveness are complementary dimensions of supply chain performance, which are analytically different. Lastly, the focus on Saudi Arabia provides useful theoretical perspectives of the supply chain conduct in emerging economies. The geographic range and the industrial variety of the country serve as a good background to the study of the interaction between the spatial complexity and the capacity to perform. The results imply that the firms working in those types of settings must have a strategic investment in responsiveness to reduce the structural risks of spatial complexity (Duysters and Lokshin, 2011; Contractor et al., 2010; Osawa and Akamatsu, 2020), and, therefore, the external validity of the existing theories of supply-chain is applicable to the settings that are not identified by developed economies.

6.2. Practical Implications

This research paper provides practical value towards supply chain management since it gives clear directives that managers who are keen on building the resilience and robustness of spatially intricate supply chains will adopt. The results highlight the need of companies to systematically evaluate the trade-offs between strategic benefits and operational risks of dispersion that arise due to spatial complexity, and to develop specific compensation strategies to the negative impacts of dispersion. In practice, this requires the deliberate spending in its capabilities that intensify supply chain responsiveness, which includes superior information systems, dynamic logistics plans, and strong relationships with suppliers and customers (Stekelorum et al., 2022). With the help of such investments, the firms can manage to coordinate the spatially intricate networks more effectively and react more efficiently to emergent disruptions.

The findings also emphasize the merits of developing a proactive disruption orientation, in which companies seek to recognize and evaluate potential disruption threats and risks instead of taking a reactionary stance after they have happened (Blackhurst et al., 2011). Anticipatory risk evaluation, contingency planning and scenario-based preparation improves the ability of the firms to absorb shocks and maintain operational performance. It therefore follows that supply chain management ought to assume a holistic outlook that does not rely on efficiency-based decision-making but rather adopt a combined approach of resilience and robustness. In line with it, the companies are advised to abandon a paradigm centered on narrowly focusing on costs reduction and adopt a more balanced model that considers long-term sustainability and supply chain performance (Queiroz et al., 2021; Stevens and Johnson, 2016; Yu et al., 2019).

It is worth noting that the results challenge traditional premises on the performance implications of spatial complexity (Peng and Kathuria, 2021). Spatial complexity in high amounts, in combination with strong abilities of responsiveness, does not equally impair resilience and robustness, thus complicating simplistic generalizations about dispersion. This highlights the need to study the interaction between disparate supply chain characteristics. Further, the research paper complements the formation of the sophisticated models of supply chain performance in the context of geographically spread conditions as emphasized by Scholten et al. (2019). Incorporating the concept of resilience, robustness, and responsiveness into the single framework, the research provides a more comprehensive view of the dynamics in the supply chain and contributes to the development of efficient managerial strategies to deal with the issue of spatial complexity (Ambulkar et al., 2014; Durach et al., 2015; Kamar, 2023; Gomera and Mafini, 2020; Scholten et al., 2019; Alvarenga et al., 2022;

Future managerial practice and research are also involved in the results. The focus on the responsiveness and active orientation of disruption makes the study produce actionable information that can be utilized by firms to enhance resilience, robustness, and competitive location. At the same time, it sets up possibilities of further research on which types of responsiveness would be most useful in counteracting the adverse performance connotations of spatial complexity. Future study can also focus on how the contextual factors such as industry nature and cultural differences, can moderate the spatial complexity-performance relationship. Longitudinal designs may offer some insight into the supply chain development under changing circumstances in the global context (Chen et al., 2014; Remko, 2020; Houshyar et al., 2013; Simchi-Levi et al., 2018; Xu et al., 2020; Blos et al., 2014; Azadegan et al., 2019; Blackhurst et al., 2018; Koh et al., 2019).

In addition to the practice on the firm level, the findings have serious implications on the policy level in relation to the national supply chain development programs. Due to the progress of the agenda of diversification and modernization of Saudi Arabian infrastructures based on Vision 2030, the increase in resilience and robustness in spatially scattered supply chains is a central policy concern. The paper highlights the importance of supply chain responsiveness to avoid the negative impact of spatial complexity, and policymakers may foster resilience with the help of investment in digital solutions, sophisticated analytics, and interoperable online logistic services that enable agility and real-time decision-making. These were particularly relevant in such strategic areas like healthcare, energy and food security.

Also, harmonization of regulations between regions, simplified trade and customs processes, and institutional facilitation of supply chain risk-management structures can significantly lower the complexity of operation linked to dispersion. The national responsiveness and shock resistance of supply chains could be further enhanced by the use of public-private collaboration strengthening the infrastructure and information-sharing networks. Together, these actions have the potential to convert the spatial complexity into the structural vulnerability to the competitive advantage on the national level.

6.3. Managerial Implications

The results of the present research highlight the crucial importance of the managerial decision-making process in dealing with the challenges introduced by spatial complexities and the effects that it has on the resilience and robustness of supply chain. The managers should be aware that the spatial complexity has both a direct and indirect impact on the supply chain performance with responsiveness playing a decisive role of mitigation. Although spatially intricate supply chains can provide an opportunity to have numerous resources and markets, they also expose coordination pressures and performance risks that require a conscious management intervention (Xiao et al., 2018; Duong et al., 2019). As a result, managers are made to consider a strategic approach to supply chain design that weighs the pros and cons of dispersion strategically.

One of the salient managerial implications that stand out of this work is the identification of responsiveness as an essential shock-absorbing attribute that takes the edge of the adverse impact of spatial complexity on the validity of resilience and robustness (Gan & Grunow, 2015). Investments that focus on increasing responsiveness in the sense of expedient decision-making, enhanced coordination systems, and responsive operational processes, should not be viewed as simple aspects of operational improvements but as strategic necessities in maintaining competitiveness and reducing the risk exposure in global supply chains (Wu & Pagell, 2010; Qi et al., 2011; Mirzaei et al., 2022; Ngo et al., 2023; Demirbag and Glaister, 2010).

Operational management wise, the paper emphasizes strength as one of the fundamental areas of supply chain performance. In addition to setting up the supply chains that can recover in case of the disruption, the managers must pay attention to the stable and consistent performance of the supply chain in times of disturbance (Nand et al., 2022). Such strength requires long-term focus on operational effectiveness, process standardization, and endless improvement efforts (Gupta and Palsule- Desai, 2011). The managers are also to think about disruption spreading through interdependent activities and pre-emptively acquire mitigation plans to restrain the ripple effect (Boonsothonsatit, 2017). In this respect, the redundancy of capacity, supplier diversification, and flexible manufacturing systems are worthwhile managerial inputs towards increased robustness (Tiwari et al., 2015).

Besides, to handle spatially complex supply chains, an organizational environment focused on operational excellence must be developed. Employees are supposed to be empowered by managers to pick up early warning signs and correct disruptions before escalating into significant crisis points (Andelkovic and Milovanovic, 2021). This involves setting concise performance measures, regular practices of communication, and organizational dedication to learning and constant enhancement (Pagell and Shevchenko, 2014). In this regard, this research can be useful to managers who need to improve the functioning of geographically spread supply chain networks (Kumar et al., 2019).

The study offers a larger managerial viewpoint that would be compatible with the realities of the global economy by highlighting the unique but complementary roles of responsiveness, resilience, and robustness as guiding principles of the supply chain management. Managers are advised to focus on investment in responsiveness capabilities, models of risk-management and operational-excellence culture to cope with spatial complexity (Gnanendra and Iacocca, 2015). By putting such strategies into place, companies can deal with the issues surrounding spatial complexity and have resilient, strong, and competitive supply chains that can function under uncertainty (Eskandarpour et al., 2015).

Lastly, the results reveal that supply chain strategies should be revised and adapted on an ongoing basis. To maintain the competitive position and reduce potential risks, managers are advised to review the existing policies in the supply chain frequently and adjust them according to different circumstances in the world (Hong et al., 2015; Bouzembrak et al., 2011). The modern global business environment is interdependent and unpredictable, and the long-term sustainability is impossible without adopting a dynamic method of supply chain management (Liu & Wang, 2014).

6.4. Limitations and Future Research

Like any other empirical research, this study may be limited in some way, which should be discussed, and, at the same time, it opens opportunities of the research that can be performed in the future. To begin with, the study is only limited in its empirical context to the firms operating in Saudi Arabia, which is an emerging economy with unique geographic, institutional and economic characteristics. Although the given focus provides helpful insights into how the spatial complexity affects the supply chain resilience, robustness, and responsiveness in such environment, it potentially limits the generalizability of the results to other countries or even regions with a different structure.

The next wave of research can address this weakness by expanding the results of the current study to the firms that are in a wider range of economic and geographic environments such as developed economies and other rising markets. Cross-country or cross-regional studies would allow the researcher to determine whether the relations found in this research are generally applicable across scenarios or they are reliant on institutional, infrastructural or cultural circumstances. These extensions would also help to identify possible moderating factors that influence the influence of the spatial complexity on the performance of the supply chain.

Second, it is a cross-sectional research design which is a single point in time relationship. Although it is suitable in testing the proposed theoretical relationships, it is not the best in reflecting dynamic development of supply chain structures and capabilities. The longitudinal research designs may help clarify the evolution of the spatial complexity, responsiveness, resilience, and robustness as they co-evolve throughout time, especially when responding to the recurrent disruptions or changing the global business environment.

Lastly, the further disaggregation of the concept of responsiveness by looking at dimensions or mechanisms through which it is conducted could be studied in future research. Finding out what forms of responsiveness capabilities, e.g., informational, operational, or relational responsiveness, prove to be most useful in ameliorating the disadvantages of spatial complexity, would add to a more subtle description of supply chain adaptation. Collectively, these avenues provide good opportunities of fronting forth theory and practice in the study of spatially complex supply chains.

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