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The Impact of Geographic Dispersion on Supply Chain Resilience and Robustness: The Role of Responsiveness

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Abstract

This study investigates the impact of geographic dispersion on supply chain resilience and robustness, focusing on the mediating role of responsiveness. Employing a deductive and quantitative approach, data were collected through an online survey administered in November 2024 to 98 employees across eleven key sectors in Saudi Arabia, including Consumer Goods, Food and Beverages, Banking, and others, representing a 100% response rate and encompassing various company sizes. Established scales were adapted to measure geographic dispersion, resilience (based on Pettit, Croxton, and Fiksel's work), robustness, and responsiveness. Statistical methods, including correlation and regression analysis, were utilized to test the hypothesized relationships. The findings show that geographic dispersion has a positive but limited effect on resilience (H1) and a marginally significant effect on robustness (H2). Responsiveness strongly mediates the relationship with resilience (H3), but its mediating effect on robustness is weak and not statistically significant (H4). The study recommends that managers prioritize investments in enhancing supply chain responsiveness through advanced information systems, flexible logistics, and strong stakeholder relationships to counteract the challenges posed by geographic dispersion and ensure supply chain stability and adaptability, particularly

within the Saudi Arabian business context.

Keywords: Geographic Dispersion, Supply Chain, Responsiveness.

1. Introduction

Businesses are going global in their operations, thus increasing the level of geographic dispersion of supply chain networks considerably. This refers to the dispersal of suppliers, production facilities, and distribution centers across different locations, in most cases across different countries or regions (Mishra, 2024). The timing and geographic spread can thus be a source of competitive advantage and result in improved cost efficiency, market access and flexibility through a multinational network, while at the same time, it can the base for a host of supply chain complications. The concept of responsiveness reappears when exploring this type of environment. Flexibility means the ability of a supply chain to respond to changes in demand or any other changes that occur. In supply chain operations that span multiple geography, the issue arises from the ease with which several locations can slow down responsiveness. Longer response times to communication, lack of synchrony among various concerned parties, and generally longer cycle times can all prevent flexibility. Thus, one of the main categories of interest in this research is how geographic dispersion affects responsiveness as the manifestation of both resilience and robustness (Richey, 2021).

From this study it is evident that while geographical distribution is viewed as a source of extended market coverage and reduced overhead cost, the structure also poses challenges that may affect efficiency and responsiveness. It is expected that the findings that have been presented in this research will enlighten best practice concerning supply chain design and management regarding the roles of this interplay. They will provide organizations with practical information on improving how they carry out their operations in dispersed locations, with the goal of increasing the

adaptability to unforeseen situations and sustain competitive edge. This research also serves to advance the knowledge in this area, which misses information about the role of responsiveness as a means to address the problem connected to geographic dispersion; other cadastres affirm the significance of flexibility in global supply chains (Christopher, 2016; Aitken et al., 2005).

As the global supply chain continues to expand, the effects of geographic distribution on supply chain resilience, reliability, and flexibility become more critical, in the year 2023 (Slam, 2023). The purpose of this research is to advance the supply chain management theory and at the same time offer valuable suggestions for professionals who want to improve their supply chain activities in frequently changing environments. Solving these critical assessment questions will equip organizations with the capacity and the ability to design and develop supply chain systems that are not just lean, but also flexible and capable of cushioning organizations against disruptions.

1.1 Research Importance:

From the scientific perspective the value of supply chain management is that it contributes to the further development of existing supply chain management knowledge towards understanding the impact of geographic distribution on supply chain resilience, robustness and responsiveness. To the best of our knowledge, prior research in this area investigated individual components of these constructs, but no study examined the effect of geographic dispersion on overall performance of the supply chain system. Supply Chain Performance Management entails the use of efficiency, effectiveness, as well as adaptability that provided a basis for supply chain competitive sustainability in the global market (McAdam and McGlothin, 2002; Gunasekaran et al., 2001). A subsequent discussion of the performance dimension of geographic dispersion will aid clarify for organizations operating in the current complex and dispersed supply chain environment.

Furthermore, there are three key types of supply chain capabilities that should be differentiated: there are the strength-based models of supply chain adaptability, namely the supply chain reliability model, which is characterized by its capacity to perform well and sustain this performance regardless of the changes in operating conditions; the supply chain recovery model, which is able to withstand and recover from disruptions; and finally, the supply chain responsiveness model, which is able to enhance its performance by making adjustments in response to changes (Tukamuhabwa et al., 201 Preventing such oversight is a purpose of this study as the author postulates that comprehending how geographic dispersion interacts with these critical factors—robustness, resilience, and responsiveness—would help improve the knowledge of supply chain conditions. This, of course, has significant implications for organizations seeking to develop solutions that improve the reliability, flexibility and productivity of their supply chains within an ever-changing global context.

In particular, the focus is made on firms operating in Saudi Arabia, which is an emerging economy. It is understandable and appropriate that Saudi Arabia was selected as the focus of this research because of its geographical and economic position. Saudi Arabia has a vast geographical region and industries located in different areas of the country, and all their supply chain networks expose them to significant risks in the Middle Eastern region. This phenomenon is ideal for understanding the effects of geographic dispersion of supply chain on its resilience, responsivity and robustness, with Robustness being define as the ability of the supply chain to remain stable and perform to its optimum in any sphere of challenge. Hence, do consider the incorporation of robustness into the assessment vital for identifying how such supply chains in Saudi Arabia can not merely survive and overcome adverse circumstances but also sustain steadiness in Saudi Arabia (Yusuf, 2023).

Moreover, the sensitized results may catalyse the emergence of new approaches to quantifying the susceptibility of supply chain networks and the identification of

recovery strategies. From the observation made in the study about the impact of geographic dispersion on supply chain performance, the research can help in the development of models that depict the performance of supply chain in the external environment. These models include risk management models that track the propagation of external risks in supply chains, such as political instability or natural disasters; Global Supply Chain Network Models, which optimize supply chain design, considering global risks and trade barriers; Supply Chain Resilience Models, like the Resilience Index to assess the ability to recover from disruptions; Simulation Models, such as Monte Carlo simulations, which predict the impact of uncertain external conditions; and Decision Support Systems (DSS), integrating internal and external data for real-time decision-making within the dynamic environment.. These models enable businesses to better manage risks and improve their supply chain performance despite external challenges (Giannakis & Papadopoulos, 2016; Meixell & Gargeya, 2005; Agarwal, Seth, & Agarwal, 2022; Oberkampf, DeLand, Rutherford, Diegert, & Alvin, 2002; Coito et al., 2021).

This may lead to articulating better theories that would be more appropriate for the ever-changing nature of global supply chains, enhancing organizational preparedness and response plans. As an example, previous literature has called for more complete assessment tools that consider both risks and protective factors. (Jüttner & Maklan, 2011; Behnam & Ramesh, 2020).

Practical Importance:

On this practical premise, this study responds to the fundamental issues on how complex and dispersed supply chain environments can be managed and supported. With the geographical diversification of operations, business organizations are confronting higher levels of operational risks in the form of disruptions, changes in regulatory requirements, and differentiated economic environments. The knowledge created from this study could provide useful tactics to supply chain managers to

increase the levels of resiliency and reliability in their operation. By positing responsiveness as a solution of geographic dispersion, the study provides practical solutions that can be adopted by an organization in enhancing communication and cooperation in their supply chain networks (Emrouznejad, 2023). For instance, responsiveness would require that more of the modern technologies be utilized to further enhance real-time monitoring and analytics for driving a long way toward making organizations agile to act on challenges at an incredible speed (Asamoah et al., 2021). The final point is the practical relevance of the findings that can be generated in this research. This may indicate an increase in supply chain robustness together with adaptability, enabling organizations to counter adverse shocks and to leverage new opportunities in the increasing uncertainty of the global business environment.

1.3 Research Aims:

The Main Objective of the Study:

The first objective is to ascertain whether geographic dispersion affects supply chain responsiveness and the aspects of responsiveness that are influenced by dispersion. This general objective aims at establishing how the supply chain components partitioned geographically affect the organization's ability to respond to disruption and recovery. Analyzing this relationship, the study has the purpose of enriching the understanding of the modern supply chains' challenges in the context of globalization. Knowledge of the relationship between geographic cues and resilience and robustness may allow for improving the efficiency and competitiveness of organizations in conditions of growing uncertainty.

Sub-Objectives of the Study:

1. Analyze the Relationship Between Geographic Dispersion and Supply Chain Resilience.

2. Analyze the Relationship between Geographic Dispersion on Supply Chain Robustness.
3. Investigate the Role of Responsiveness in Mediating Geographic Dispersion Effects.

1.4 Research Question:

Main Study Question:

How does geographic dispersion impact supply chain resilience and robustness, and what role does responsiveness play in this relationship?

Sub-Questions:

1. What are the specific effects of geographic dispersion on the resilience of supply chains?
2. In what ways does geographic dispersion influence the robustness of supply chains?
3. How does responsiveness mediate the relationship between geographic dispersion and supply chain resilience and robustness?

2. Theoretical Background

2.1 Geographic Dispersion:

Supply chain dispersion means the practice of distributing various tasks in a supply chain across different locations, and more often geographical ones (Ojha et al., 2018). It has a current relevance as organizations seek to enhance operational efficiency, identify different target customers and address various risks. The following benefits can be associated with the geographical diversification of operations: Companies seek efficiencies on costs, resources and market reach (Chor & Alfaro, 2023).

A significant challenge in supply chain management arises from the difficulty of matching supply and demand across large distances, compounded by varying regulations in different countries and regional risks such as natural disasters and political instability. For example, in response to increasing trade tensions between the US and China, many organizations adjusted their supply chain strategies by moving away from globalization. This shift led to a preference for nearshoring, with countries like Vietnam and Mexico emerging as key alternatives. As a result, most companies prefer nearshoring over globalization to reduce risks (Alfaro & Chor, 2023; Saisridhar, 2023).

The threats to nearshoring include factors such as high production costs, lack of local expertise, and risks related to localization. In contrast, the opportunities include advantages like lower operational costs, access to regional expertise, and proximity to growing markets, which differentiate it from the benefits of globalization, such as economies of scale and broader market access. Dispersing geographic locations within a supply chain helps enhance its reliability by diversifying the sources of supply. This geographical spread reduces dependency on any single region, minimizing the risk of disruptions caused by local factors such as natural disasters, political instability, or other region-specific issues. For instance, Apple has a complex and integrated supply chain network that extends across several countries of the world, thus is able to take advantages of strength such as availability of labor and technology. However, disruptions in the key areas, for example, a shortage of semiconductor materials due to the outbreak of COVID-19 led to Apple's search for additional locations such as India for production (Saisridhar, 2023).

2.2 Supply Chain Resilience:

Supply chain resilience is the capacity that supply chain networks have to prevent, handle, respond and adapt to disruptions that may occur in the chain's course,

resulting from events like natural disasters, political instabilities or shifts in the economic landscape (Tukamuhabwa et al., 2015). One effective solution is the business continuity management, which allows an organization to keep functioning and reduce the consequences of such events for customers and other aspects of operation. On the other hand, operational supply chain robustness is the ability of a supply chain to perform optimally under unfavorable circumstances by adopting measures such as duplication and other inventory control techniques. The search for reasons for these changes and disclosure of the relationship between resilience and robustness is literally what stands in front of businesses seeking to work under the conditions of a global environment (Mackay et al., 2020).

Different theoretical lenses highlight various facets of resilience. The Resource-Based View, for instance, emphasizes internal capabilities; therefore, firms in possession of resources that are valuable, rare, inimitable, and non-substitutable are capable of much quicker shock absorption and fast recovery. This framework, therefore, suggests that flexibility in manufacturing process investments, robust IT infrastructure, and a competent work force are the areas to enhance resilience. The Dynamic Capabilities Perspective develops this further, where the possession of valuable resources by the firm is not enough but has to be reconfigured and adapted to changed circumstances. Such dynamic adaptation involves sensing the emergence of threats and opportunities, seizing advantageous positions, and reconfiguring operations to sustain effectiveness in disrupted environments. These internal, firm-level factors are crucial for building a foundation of resilience (Rincón and Sarache, 2024; Atieh et al., 2024; Odulaja et al., 2023; Dai et al., 2024).

Although there has been a considerable body of literature that has explored the importance of engineering resilience and adaptation, the studies examining resilience as transformation remain limited. Today's disruptions are social-

ecological disruptions that warrant new methods of containing the disruptions (Visnic et al., 2024).

2.3 Supply Chain Robustness:

Supply chain robustness is a related concept that deviates from supply chain resilience in that it emphasizes consistent supply chain performance under changing conditions especially when facing risks and geography. While resilience deals with a supply chain's capability to bounce back from disruptions, robustness focuses on maintaining operating efficiency in the face of disruption while being immune to disruptions that may cause changes.

Supply chain resilience is more crucial as far as operation risks and stability during volatile conditions are concerned. Shishodia et al. (2023) defines robustness as the ability of the supply chain networks to withstand risks and pressures without compromising the performance significantly. This is different from resilience that deals with the process of restoring order after disruption. The systems have to be resistant in such a way that they do not collapse and this is especially so where the working units are set up in different areas. That way, geographic dispersion creates additional risks for supply chains, including inconsistent regulatory requirements, variability in infrastructure, and diverse physical environments, making robustness one of the key supply chain design dimensions.

The impact of geographic dispersion is now more evident in the resilience of supply chains. This implies that geographical factors including distance between supply chain nodes and variability of regional characteristics constitute potential sources of supply chain disruption. It has also been ascertained that supply chain operations that are geographically decentralized are vulnerable to disruption because a problem that arises in one location will be felt in other locations along the chain. To mitigate these threats, firms require sound strategies, for instance, working with

various suppliers, scaling up real-time data processing, and improving the delivery of supplies to sustain performance (Munim et al., 2023).

Some examples of supply chain resilience are leading multinational corporations such as Apple and Toyota who not only maintain multiple levels of suppliers but they also ensure regular supply chain performance. These companies' supply chain is structured in a way that it doesn't stop functioning even if it is facing some sort of disruption, and as we know from the above observation, robustness is always associated with sustainability which is the ultimate goal. Apple for instance developed business partnerships with multiple suppliers of critical components to guarantee operations in case of disruptions in one supplier. When it comes to Toyota lean production, it is pointed out that principles of robustness involve minimizing waste and adding resilience into production processes (Sharma et al., 2023).

The idea of supply chain reliability has recently gained considerable interest because of the disruptions including the COVID-19 that exposed the weaknesses of the geographical supply chain networks. Fuzzy decision-making models such as Fuzzy TOPSIS and Fuzzy CRITIC have been employed to assess the resilience of SCs under such situations. These models evaluate the resilience of firms in relation to disruptions and based on the degree of geographical and operational risks (Rajesh et al., 2021).

2.4 Supply Chain Responsiveness:

In supply chain systems, responsiveness means the capacity of supply systems to execute swift and effective adjustments to demands, supplies, or other market conditions. It is a key factor in a company's viability in dynamic situations, even more in today's global environment, where timely and effective responses are of tremendous importance. Responsiveness refers to the ability of supply chain actors to change supply chain activities regarding consumer demands, supplier dynamics,

or other unforeseen circumstances; this has become critical in SC performance (Gunasekaran et al., 2018).

Geographical dispersion has a direct effect on responsiveness. On one hand, dispersed supply chain may have issues of coordination across the different regions making decisions and implementing changes across various regions slow. Coordination between several offices with different jurisdictions and spans across different time zones can limit the capability of rapidly responding to new changes. For instance, companies situated in different continents may be a big problem of matching inventory, logistics and communication across far-off markets, making the whole business less responsive (Christopher & Peck, 2020). Finally, geographically dispersed supply chains can access a broader supplier network and markets; which supply chain dynamics often makes it easier to switch between suppliers and markets when disruptions are encountered. Potential that exists in the dispersed supply chain system is the possibility of several nodes in different areas, which makes it easier to reroute and source for materials where a particular area has been affected (Lorentz et al., 2012).

Responsiveness correlates with resilience and robustness as well: the correlations proved to be significant. Whereas resilience concentrates itself on recovering from disruptions, responsiveness ensures that supply chain can respond appropriately to prevent or reduce the degree of a disruption. In this sense, responsiveness can boost the resilience of supply chains since these can prepare for change before they occur (Gligor et al., 2020). Furthermore, responsiveness can also affect the other component referred to as robustness which concerns itself with the ability of the system to perform efficiently under different conditions. The ability to move resources or production processes faster in response to interruption can help to sustain operations; this contributes to supply-chain responsiveness and helps to

offset the disadvantages of dispersion that are inherent in geographic risks (Seifzadeh, 2017; Lynch, 2016).

2.5 Factors Influencing Supply Chain Resilience and Disruption Orientation:

Supply chain resilience results from the interactive and complex combination of internal and external influences. These internal factors encompass strategic decisions on supplier diversification, inventory management strategies, such as buffer stock levels or just –in -time versus just –in -case, technological capabilities that include real-time visibility and predictive analytics, and the robustness of the information system. In contrast, the stronger external influences include geopolitical instability, natural calamities, pandemics, economic fluctuations, and changes in regulations. It is vulnerable to disruption based on three major variables: geographical concentration of the supply chain, dependence on single-source suppliers, and complexity of the network. Understanding these interacting elements is crucial for developing effective resilience strategies (Atieh et al., 2024; Birkie et al., 2017; Bag et al., 2019; Singh, 2024)

The concept of disruption orientation deals with proactive risk assessment and mitigation strategies, which have intrinsic relations with supply chain resilience. Firms characterized by a high level of disruption orientation are those capable of actively identifying potential points of vulnerability in their supply chains and creating contingency plans or investing in technologies and processes that enable agility and adaptability. This proactive approach contrasts with a reactive approach whereby firms respond to disruptions only in their aftermath. Furthermore, disruption orientation necessitates deep understanding from firms regarding how the mechanism of risk cascading across the supply chain network takes place and also how collaborative relationships can be developed with suppliers, logistics providers, and any other relevant stakeholders to effectively respond to unforeseen events. It is, therefore, this very orientation of a firm that enables it to survive

disruptions but at the same time be successful in dynamic and uncertain environments (DuHadway et al., 2019; Rinaldi et al., 2022; Jiang et al., 2024; Golgeci and Ponomarov, 2013).

3. Conceptual Model and Research Hypotheses

3.1 Relationship between Geographic Dispersion and Supply Chain Resilience:

Geographic dispersion, defined as the strategic distribution of supply chain activities across diverse geographical locations, can introduce inherent vulnerabilities in the face of unforeseen disruptions. While offering potential benefits such as access to specialized labor pools, lower production costs, and proximity to emerging markets (Chor & Alfaro, 2023), it simultaneously increases the complexity of managing the supply chain. The literature reviewed so far has focused on some of the potential disadvantages of dispersion: for example, added managerial complexities due to activities being coordinated across different locations, time zones, and cultural contexts.

Regulatory differences among regions demand compliance with various legal frameworks that further stress management resources. Geographically dispersed supply chains are significantly more exposed to local risks in the form of natural calamities, political instability, including trade wars and policy changes, and infrastructural limitations that may arise (Alfaro & Chor, 2023; Saisridhar, 2023). These can badly affect the capability of a supply chain to absorb shocks, to adapt rapidly, and to recover effectively from its disruption, hence making it less resilient overall. Although theoretically, diversification of supplier locations could improve resilience by making firms less dependent on single sources, this strategy has been pursued by Apple, for example; however, added complexity and difficulties in maintaining seamless coordination often offset this potential benefit. This delicate

balance between the diversification benefits and the increased risks associated with dispersion forms the basis for the following hypothesis:

H1: Geographic dispersion negatively affects supply chain resilience.

3.2 Relationship between Geographic Dispersion and Supply Chain Robustness:

The negative effects of geographic dispersion, in that sense, may concurrently pose adverse impact on the robustness of supply chains. This definition of robustness-but, in a supply chain perspective-sets it apart from resilience as this could be described by an aptitude to continue the same performance during variable or even unfavorable circumstances by absorbing the imposed variability due to the exertion of pressures with the absence of overall performance deterioration (Shishodia et al., 2023). It would seem that the literature views geographically dispersed supply chains as inherently more variable and inconsistent. They most often operate under different and sometimes inconsistent regulatory requirements in disparate jurisdictions that require specific adaptation and, therefore, elevate the costs of compliance. Variability in infrastructure across locations might cause logistical chokepoints and delays, apart from increased transportation costs. In addition, diverse physical settings present different risks around climate, natural resources, and local infrastructures that can affect efficiency and reliability in production (Munim et al., 2023). These inherent vulnerabilities intrinsically come with a geographically dispersed nature of operation and compromise the ability of the supply chain to maintain stable and consistent performance. This rationale leads to the following hypothesis:

H2: Geographic dispersion negatively affects supply chain robustness.

3.3 The Mediating Role of Responsiveness: Geographic Dispersion, Resilience, and Responsiveness:

Gunasekaran et al. (2018) defined supply chain responsiveness as the capability to respond efficiently and in a timely manner to altered demand, supply conditions, or unexpected changes in the market. The relationship between geographic dispersion and resilience is mediated by supply chain responsiveness. While geographic dispersion creates some natural barriers to resilience, a very responsive supply chain can substantially offset these negative effects. A responsive system has the agility to react in a proactive way and make necessary adjustments to dispersion, such as switching off materials through other channels more quickly or even switching between different suppliers more rapidly, and adapting their internal processes with greater urgency. The responsiveness of supply chains increases the ability of a supply chain to understand, anticipate, and make appropriate responses to changed conditions, thus mitigating many of the effects of dispersion on resilience. In that case, a responsive supply chain can use its agility more easily to overcome the coordination challenges, adapt to the regulatory variations, and mitigate risks that are localized. Responsiveness enhances the preparedness of a supply chain to disruption and its effective recovery (Gligor et al., 2020). The theoretical underpinning that this provides forms a basis for the following hypothesis:

H3: Responsiveness positively mediates the relationship between geographic dispersion and supply chain resilience.

3.4 The Mediating Role of Responsiveness: Geographic Dispersion, Robustness, and Responsiveness:

The mediating role of responsiveness also extends into the relationship between geographic dispersion and robustness. This is a responsive supply chain-one that

has gained the ability to gain flexibility in operations and agility regarding changes that might come around. That would be the ability for flexible allocation of resources, rapid changes in productions, and dynamic logistical adaptations that responsiveness so much advances the capacity of the supply chain to resist pressures, absorb variability, and maintain performances despite having to face diverse contexts of operations (Gligor et al., 2020). The ability to quickly adapt to changing regulatory landscapes, infrastructural limitations, and local disruptions is central to maintaining robustness in operations across geographical dispersion. This dynamic interplay among dispersion, robustness, and responsiveness leads to the following hypothesis:

H4: Responsiveness positively mediates the relationship between geographic dispersion and supply chain robustness.

4. Methodology

4.1 Research Approach:

It will be a quantitative and deductive approach. This approach allows the study to test pre-existing theories linked to supply chain resilience and robustness, particularly in geographic dispersion and responsiveness. This approach involves collecting and analyzing numerical data to check for relationships between the variables using Borgstede variables (Borgstede, 2021).

4.2 Data Collection:

Data for this study was collected by conducting a survey among employees in Saudi Arabia. The design of the survey instrument was done with utmost precision, capturing as many details about geographic dispersion, supply chain resilience, robustness, and responsiveness across various sectors.

To ensure a representative sample across various industries, the survey targeted employees from eleven key sectors: Consumer Goods, Food and Beverages, Banking, Hospitality and Consulting, Consumer Electronics, Pharmaceuticals, Energy and Utility, Shipping and Logistics, Apparel and Textile, Automotive, Construction, and other industries. The survey was conducted online, and participation was solicited in November of 2024.

The response rate stands at 100%, thereby guaranteeing a sample of 98 employees. In regard to this, the high data participation rate will ensure a high degree of reliability in the resultant data while minimizing the risk of response bias. The sample included a diverse range of company sizes, including Large Enterprises with 250 or more employees, Medium Enterprises with 50-249 employees, Small Enterprises with 10-49 employees, and Micro Enterprises with 1-9 employees, thus providing a proper balance in the representation of the Saudi Arabian business landscape. This further enhances the generalizability of the findings to a broader range of organizations operating within the Kingdom.

4.3 Measures:

Established scales and measures were adapted and integrated into the present study to capture the complex interaction of geographic dispersion, resilience, responsiveness, and robustness of supply chains.

In measuring the supply chain resilience, we have adopted the work of Pettit et al. (2013) and adapted this scale to the challenges firms faced in the wake of the

COVID-19 pandemic. This measurement uses a five-point Likert scale, with "completely disagree" and "completely agree" as the anchoring statements, to measure the resilience of firms in unprecedented disturbances.

To capture the strategic importance of the responsiveness of supply chains, we adopted items from Christopher and Peck (2004), focusing on strategic priorities for a company's main product line. This measurement scale also utilizes a five-point Likert scale, ranging from "not important at all" to "extremely important." This indicates the extent of responsiveness that a company pursues in the context of its overall supply chain strategy.

Its application to measure the impact of external shocks on the subjects was inspired by related approaches from Hendricks and Singhal [14]. Respondents evaluated the impact of such events along various dimensions, namely: turnover, efficiency, delivery times, procurement costs, number, and well-being of workers. There is a five-point scale from "a very large negative impact" to "a very large positive impact" capturing the wide-ranging consequence of disruptions.

Following the approach of Craighead et al. (2007), geographic dispersion 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):

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

This formula yields a measure of dispersion that varies between 0 and 1, where 0 corresponds to complete concentration in one region, and 1 corresponds to equal distribution across all regions.

To further reinforce the robustness of our analysis, we also included measures of logistics outsourcing, adapting the approach by Ellram and Tate (2004). This involved asking respondents to indicate the extent to which their firms outsourced various activities in logistics on a five-point Likert scale, hence capturing the degree of reliance on external partners for critical supply chain functions.

Finally, realizing the potential influence of firm size and considering the sphere of industry in which supplies are obtained may affect chains of supply, we added controls for these factors in our study. Firm size based on reported annual turnover was in categories, while industry was by dummy variables for sectors, which are encoded. These controls extend our analysis to account for possible variations in these associations between our main constructs along different company sizes and through various industry sectors.

By integrating these different measures and scales, we seek to comprehensively capture the complex relationships that exist among geographic dispersion, supply chain resilience, responsiveness, and robustness in light of external shocks and disruptions.

4.4 Model:

To test our hypotheses, we employed a regression analysis 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 geographic dispersion, we established the following formulation:

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

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 Geographic Dispersion (G), 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:

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

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.

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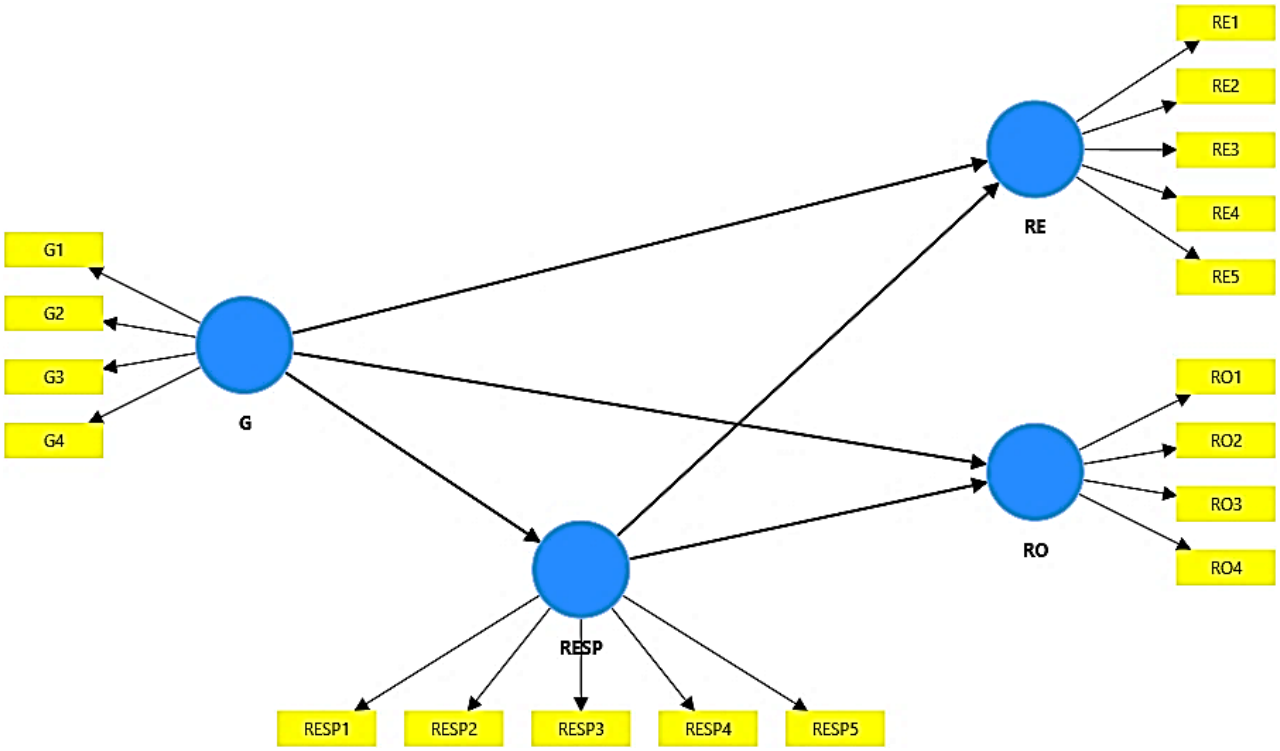

Figure (1): Research model

5. Results

Table 1 presents the research variables and constructs used in our study. To assess the validity and reliability of the measurement scales, we conducted Confirmatory Factor Analysis (CFA). The variable RE4 was dropped from subsequent analyses due to its negative factor loading (-0.025). Additionally, RESP4 and RESP5 exhibited low factor loadings (0.348 and 0.223 respectively), while RO2 and RO4 showed insufficient loadings (0.267 and 0.193 respectively), leading to their removal from further analysis.

We then assessed the fit of the factor model using commonly recommended indices: the comparative fit index (CFI), Tucker-Lewis index (TLI), chi-square value (χ^2), and

root mean square error of approximation (RMSEA). Convergent validity, reliability, and internal consistency were evaluated by examining average variance extracted (AVE) and composite reliability (CR) values. The Geographic Dispersion (G) construct demonstrated adequate convergent validity with AVE = 0.39 and CR = 0.711, with factor loadings ranging from 0.492 to 0.739. For the Supply Chain Resilience (RE) construct, despite a lower AVE of 0.231, the CR value of 0.534 was deemed acceptable for exploratory research, with significant factor loadings between 0.468 and 0.663.

The Supply Chain Responsiveness (RESP) construct showed moderate convergent validity with AVE = 0.273 and CR = 0.623. The highest factor loadings were observed for RESP1 (0.686) and RESP2 (0.664), indicating strong measurement of supply security and inventory management aspects. Similarly, the Supply Chain Robustness (RO) construct, with AVE = 0.265 and CR = 0.531, demonstrated acceptable reliability. RO3 exhibited the highest factor loading (0.781), suggesting that the ability to absorb negative impacts from recurrent risks is a key indicator of supply chain robustness.

Table 2 presents descriptive statistics and correlations among the key constructs in our study. The means of all constructs were above the scale midpoint, ranging from 3.037 to 3.298, suggesting generally positive assessments of supply chain capabilities across the sample. Supply Chain Responsiveness showed the highest mean (3.298, SD = 0.742), while Supply Chain Resilience had the lowest (3.037, SD = 0.689).

The correlation analysis revealed significant relationships between most constructs. Geographic Dispersion demonstrated positive correlations with all other constructs: Supply Chain Responsiveness ($r = 0.301$, $p < 0.01$), Supply Chain Robustness ($r = 0.273$, $p < 0.01$), and Supply Chain Resilience ($r = 0.227$, $p < 0.05$). A particularly strong correlation was observed between Supply Chain Resilience and Robustness (r

= 0.471, $p < 0.01$), suggesting these capabilities may be complementary. Supply Chain Responsiveness showed a significant correlation with Resilience ($r = 0.335$, $p < 0.01$) but a weaker, non-significant relationship with Robustness ($r = 0.183$, $p > 0.05$).

Table 3 presents the results of our regression analyses testing the research hypotheses. The impact of Geographic Dispersion on Supply Chain Resilience ($\beta = 0.197$, $t = 0.939$) was positive but not statistically significant, providing limited support for H1. Geographic Dispersion showed stronger effects on Supply Chain Responsiveness ($\beta = 0.304$, $t = 1.865$) and Robustness ($\beta = 0.386$, $t = 1.895$), though these relationships were only marginally significant at $p < 0.10$, partially supporting H2 and H3.

Supply Chain Responsiveness demonstrated a significant positive effect on Resilience ($\beta = 0.454$, $t = 2.103$, $p < 0.05$), strongly supporting H4. However, its impact on Robustness was negligible ($\beta = 0.03$, $t = 0.115$), failing to support H5. The F-statistics further confirmed these relationships, with the strongest effect observed for Responsiveness on Resilience ($F = 0.242$).

The model explained 22.6% of the variance in Supply Chain Resilience ($R^2 = 0.226$), 15% in Supply Chain Robustness ($R^2 = 0.150$), and 9.2% in Supply Chain Responsiveness ($R^2 = 0.092$). 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.

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Table (1): The research variables and constructs

Research construct	Description and references	AVE/CR loading
Geographic Dispersion (G)		0.39/0.711
G1	Our company relies more on production sources from diverse geographic regions than on production concentrated in one geographic region	0.492
G2	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
G3	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	0.721
G4	Our company's sales are distributed across multiple geographic regions rather than being concentrated in one geographic region	0.5
Supply Chain Resilience (RE)		0.231/0.534
RE1	We are able to adequately respond to unexpected disruptions by quickly restoring our product flow	0.512
RE2	We are well prepared to deal with the financial outcome of potential supply chain disruptions	0.468
RE3	We are able to provide a quick response to a supply chain disruption	0.663
RE4	We are able to adapt to a supply chain disruption easily	-0.025
RE5	We are able to cope with changes brought about by a supply chain disruption	0.483
Supply Chain Responsiveness (RESP)		0.273/0.623
RESP1	Enhancing supply security	0.686
RESP2	Maintaining safety inventory of work-in-progress or finished products	0.664
RESP3	Retain excess capacity in manufacturing	0.53
RESP4	Respond quickly to unpredictable demand	0.348
RESP5	Increase frequency of new product introductions	0.223
Supply Chain Robustness (RO)		0.265/0.531
RO1	Our supply chain and logistics networks can remain effective and be sustained even when internal/external disruptions occur	0.583
RO2	Our supply chain and logistics networks can avoid or minimize risk occurrences by anticipating and preparing for them	0.267
RO3	Our supply chain and logistics networks can absorb a significant level of negative impacts from recurrent risks	0.781
RO4	Our supply chain and logistics networks have sufficient time to consider the most effective reactions	0.193

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Table (2): Key Statistics of Constructs

Construct	Mean	Std. Deviation	Geographic Dispersion (G)	Supply Chain Resilience (RE)	Supply Chain Robustness (RO)	Supply Chain Responsiveness (RESP)
Geographic Dispersion (G)	3.163	0.874	1	0.227*	0.273**	0.301**
Supply Chain Resilience (RE)	3.037	0.689	0.227*	1	0.471**	0.335**
Supply Chain Robustness (RO)	3.069	0.728	0.273**	0.471**	1	0.183
Supply Chain Responsiveness (RESP)	3.298	0.742	0.301**	0.335**	0.183	1

Table (3): Results of regression analyses

Path	B (T)	F		
		RE	RESP	RO
G -> RE	0.197 (0.939)	0.004		
G -> RESP	0.304 (1.865)		0.102	
G -> RO	0.386 (1.895)			0.152
RESP -> RE	0.454** (2.103)	0.242		
RESP -> RO	0.03 (0.115)			0.001
Adj R^2		0.209	0.083	0.132
R^2		0.226	0.092	0.15

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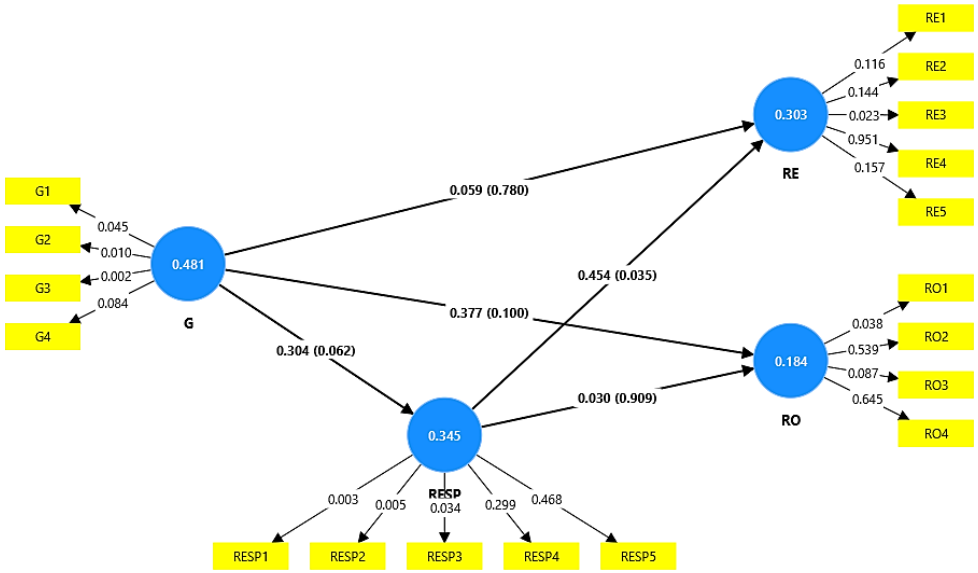

Figure (2): Research model and results

6. Discussion and Conclusions

6.1 Theoretical Implications:

This study examines the intricate relationship between geographic dispersion and supply chain resilience and robustness, with a focus on the mediating role of responsiveness (Demirbağ & Glaister, 2010). The findings provide rich insights into how the spatial dispersion of supply chain activities affects the ability of a firm to absorb disruptions and maintain consistent performance. Unlike much of the previous literature, which often considered one or two of these constructs in isolation, this research integrates them into a comprehensive framework and provides a more nuanced understanding of their interplay (Neimark & Vermeylen, 2016).

The research will, therefore, add to the literature gap in terms of responsiveness as a mitigating mechanism for the challenges related to geographic dispersion, with a focus on Saudi Arabia, an emerging economy that exhibits unique geographical and

economic characteristics. It also highlights that while geographic dispersion can offer potential advantages, like access to diverse resources and markets, it also introduces complexities that can substantially impact the performance of supply chains. These include increased coordination challenges, exposure to localized risks, and potential disruptions in information flow and communication (Choi, 2017; Hoskisson et al., 2012; Xu & Meyer, 2012).

The study's findings contribute to the theoretical understanding of supply chain resilience by highlighting the importance of not only internal capabilities but also the external context in which the supply chain operates (Belderbos et al., 2013). This research underlines that a firm has to put into consideration one of its most critical determinants that affect its shock absorption and recovery capabilities due to the geographical dispersion of a firm's supply chain activity. Besides, this present study evidences that since resilience is dynamic, change is continuously brought by moving challenges in strategy and capacities regarding geographic dispersion. By looking at the interactions of geographic dispersion, resilience, and robustness in one analysis, this study takes a far more holistic look at supply chain performance than had previously existed. It calls for companies not only to recover after having been disrupted-what some might regard as resilience-but also sustain performance despite such shocks; that is, robust. This dual focus is particularly pertinent in today's closely interconnected and volatile global environment, where supply chains are being constantly exposed to a wide array of risks (Zahra et al., 2014; Liu & Vrontis, 2017; Jacob et al., 2013; Singh, 2012; Brito, 2022).

This study contributes significantly to the literature with responsiveness as a mediator in the relationship between geographic dispersion and supply chain resilience and robustness. Responsiveness was found to be an important mechanism through which the negative effects of dispersion could be diminished. That is to say, responsiveness contributes both to robustness and resilience through rapid firm

adaptability to the changed circumstances, combined with capabilities for coordination of activities between different locations. This turns out to be an important result given the evidence it reveals about the areas where investment is needed to make capabilities promote responsiveness in firms: such advanced information systems, flexible logistic arrangements, and good supplier and customer relationships (D'Agostino et al., 2012; El-Sayed et al., 2022; Peng & Kathuria, 2021; Lo & Hung, 2014).

The focus of the study on Saudi Arabia as an emerging economy is very valuable in terms of insight into the unique challenges and opportunities that might face firms operating in such environments. Besides, the huge geographical area and diverse industries make it an ideal case to study the effects of geographic dispersion on supply chain performance. The findings imply that Saudi Arabian firms have to take into consideration the geographical dispersion of supply chain activities and invest in capabilities that enhance responsiveness, thus mitigating the risks associated with it (Duysters & Lokshin, 2011; Contractor et al., 2010; Osawa & Akamatsu, 2020).

This research also contributes to practical knowledge on how to manage a supply chain by providing valuable guidance for managers seeking to enhance the resilience and robustness of their supply chains. The findings suggest that firms should carefully assess the trade-offs between the benefits and risks of geographic dispersion and devise strategies to mitigate the negative impacts of dispersion. These activities were business investments in capabilities that enabled it to be responsive, for example, through advanced stages of information systems, flexible arrangements on logistics, and solid connections between itself and its suppliers/customers (Stekelorum et al., 2022). According to this work, appropriately developing "a disruptive orientation" through active recognition/evaluation of future disruption risk can provide relevant approaches to mitigate risks (Blackhurst et al., 2011). Anticipating disruptions and contingency

planning will help firms increase their resilience to shocks and sustain performance. This means that firms should adopt a holistic approach in managing supply chains, focusing not only on efficiency but also on resilience and robustness. It now requires a paradigm shift from the traditional approach of cost reduction to a more balanced approach of long-term sustainability and performance of the supply chain (Queiroz et al., 2021; Stevens & Johnson, 2016; Yu et al., 2019).

However, the findings run counter to some aspects of conventional wisdom regarding geographic dispersion and the ensuing performances of supply chains. The findings by that token rule out a decline in resilience and robustness due to high geographical dispersion, an opinion that was countered by some researchers. Astonishingly, the ability actually improves with a heightened feeling of responsiveness. This finding pinpoints the importance of considering the different supply chain characteristics and their respective interactions, rather than allowing oneself to fall into simplistic generalizations about the effects that dispersion may have. Besides, this study contributes toward the development of new theoretical models for understanding supply performance in the context of geographically dispersed supply chains in Scholten et al. (2019). By embedding the concepts of resilience, robustness, and responsiveness into an integrated framework, this study develops a more fine-grained and holistic understanding of supply chain dynamics.

This framework may be used as a starting point for future research in this area and will also assist managers in the development of more effective strategies that address the challenges posed by geographically dispersed supply chains (Ambulkar et al., 2014; Durach et al., 2015; Kamar, 2023; Gomera & Mafini, 2020; Scholten et al., 2019; Alvarenga et al., 2022; Messina et al.,2020; Zhou & Xu, 2012).

The results have a number of important implications for both theory and practice in supply chain management. Theoretically, this study develops complex relationships between geographic dispersion and resilience, robustness, and responsiveness. At

the same time, some of the existing assumptions are challenged; the effect of dispersion is described in greater detail. It practically provides insights to managers that are really useful to enhance the performance of their geographically spread supply chains. By emphasis on responsiveness and proactive disruption orientation, the study has provided actionable insights, which could be used by the firms in enhancing their resilience along with general robustness or competitiveness. Several avenues are opened for future research by the present research. The interactions could, therefore, be explored through more focused questioning as to what types of responsiveness capabilities exert the greatest mitigating effect on dispersion's negative performance implications. Future research could equally have a vested interest in probing how the role of other contextual factors - including but not limited to industry characteristics and cultural differences - condition the geographic dispersion-performance relationship. Longitudinal studies may provide valuable insights into dynamic changes in the evolution of supply chains with regard to changes in global conditions (Chen et al., 2014; Remko, 2020; Houshyar et al., 2013; Simchi-Levi et al., 2018; Xu et al., 2020; Blos, 2014; Azadegan et al., 2019; Blackhurst et al., 2018; Koh et al., 2019).

6.2 Managerial Implications:

Furthermore, it has emerged from research as highly important for managers in determining the effect of their business related to geographic dispersion on its supply chain resilience and robustness. The ability to apply responsiveness has a significant force towards countering challenges. It remains a fact that addressing geographical dispersion involves more or fewer issues. The following study points out that, even as geographic dispersion brings certain benefits such as access to varied resources and markets, the addition of these complexities makes a strong mark on the performance of supply chains (Xiao et al., 2018). In addition, therefore, it calls upon the managers to take strategic action with regard to supply chain

design, which carefully weighs the pros and cons of dispersion. One important implication of this is that responsiveness acts as an important shock absorber in mitigating the negative impacts of geographical dispersion on both resilience and robustness. This would mean that investments in improving responsiveness are not only operational but also strategic imperatives to achieve or sustain competitiveness and reduce risks in global supply chains (Wu & Pagell, 2010; Qi et al., 2011; Mirzaei et al., 2022; Ngo et al.,2023; Demirbağ & Glaister, 2010).

However, in more fundamental terms, the implications relate not only to responsiveness in providing a key driver of each of resilience and robustness but also to managerial behaviors pertinent to geographically dispersed supply chains. The investment priority is on capability, advanced information systems, and flexible logistics arrangements for a strong relationship with either supply partners or customers. Advanced information systems facilitate the ability of managers to monitor, in real-time, supply chain operations from various locations and quickly pinpoint areas of potential disruption. Flexible logistic arrangements, such as multimodal transportation and agile warehousing, provide firms the capability to adjust their logics operations to changed circumstances, re-routing materials when necessary.

Good communication and collaboration with the supplier and customer as well as strong relationships with suppliers and customers makes firms able to respond quickly to changes in demand or supply (Duong et al., 2019). Also, managers should create an organizational culture of responsiveness and allowing employees to make conclusions promptly and embrace changes and flexibility (Silvestre, 2023). It takes clear communication channels, decentralized decision-making authority, and a continual improvement focus (Taylor, 2023; Croom et al., 2018; Kuo & Lee, 2019; Olson & Swenseth, 2014; Blanco et al.,2011; Zhou & Xu, 2012).

The outcomes of this research are also relevant to various risk management issues in GSCs (Gan et al., 2021). Managers should understand that geographic dispersion enhances exposure to many risks such as natural calamities, political instability, and volatility within the economy (Carter et al., 2020). So, the construction of a coherent risk management plan, which addresses issues connected to dispersion, is vital (Yu & Solvang, 2016). Such measures entails the performance of risk audit, creation of backup strategies, and the provision of preeminent risk control instruments (Fichtinger et al., 2019). Managers should also examine the possible repercussion with regards to several areas in the firms' GSCC networks and develop regional contingency plans (Paksoy et al., 2010). This calls for a proper understanding of the geographical characteristics of each of these areas, the legal restraints, the physical facilities available, and the people's attitudes toward a certain kind of undertaking (Yu & Solvang, 2018). Furthermore, managers should build partnerships with suppliers and other players in the supply chain with a view of improving their handling of disruptions (Shukla et al., 2011). This covers exchange of information, synchronal planning of tasks and establishment of common emergency preparedness (Nakano, 2015; Neimark & Vermeylen, 2016).

For operational management, particularly, it has important implications because the emphasis the study places on the dimension of robustness as a key dimension of supply chain performance. In addition to building resilient supply chains that can recover from disruptions, managers should strive to that there are robust supply chains, that is, they maintain consistent performance under disruptions (Nand et al., 2022). In other words, this requires a focus on operational efficiency, process standardization and continuous improvement (Gupta & Palsule-Desai, 2011). Boonsothonsatit, (2017) suggest that managers should also be thinking of the effects of disruption on other parts of their operations and strategies to mitigate the impacts. Tiwari et al. (2015) stress this, involving redundant capacity, diversifying suppliers

and developing flexible manufacturing processes. Besides this, managers should develop an operational excellence environment in their organizations and let the employees can detect and overcome the interruptions in advance before they tip into severe crises (Anđelković & Milovanović, 2021). To achieve this, though, clear metrics of performance, the delivery of clear, regular communication and a constant learning mind are required (Pagell & Shevchenko, 2014).

Therefore, this research offers great insight in the area of supply chain management, especially for managers who need help enhancing the performance of their dispersed supply chain networks (Kumar et al., 2019). In addition, stressing the distinctiveness of responsiveness, resilience, and robustness as the primary guiding principles of supply chain management, the research presents a broader vision of SCM in the context of the global economy. Responsiveness capabilities, risk management models and culture of operational excellence should be top investment priorities for managers (Gnanendran & Iacocca, 2015). Through implementing these strategies, the firms are able to manage the problems that stem from geographic dispersion and develop strong and competitive supply chains which would suit today's unpredictable business environments (Eskandarpour et al., 2015). The study also also revealed the importance of dynamic review and evolution (Hong, Wang et al., 2015). It then becomes evident that managers should continually review their supply chain management policies and adapt to changing global situations in a bid to realize competitiveness and avoid possible risks (Bouzembrak et al., 2011). Such a dynamic model of supply chain management proves crucial for being sustained in the long run in the contemporary global economy characterized by interaction and uncertainty (Liu & Wang, 2014).

6.3 Limitations and Future Research:

The specific limitations of this study of the interaction between geographic dispersion, supply chain resilience, robustness, and responsiveness should be

acknowledged. Additionally, they also provide a direction to further research on this complicated but important area. An important limitation of the study stems from the restricted context, i.e., Saudi Arabia and an emerging economy. While this focus generates interesting insights about the problems and opportunities that firms in this unique circumstance face, it may make them less generalizable to other regions or economy with different features. Future research could expand the geographical scope by including firms from a broader range of economic and geographic settings making it possible to compare findings across regions. This would allow us to decide whether these relationships drawn from this study are true in other contexts and whether there may be moderating contextual factors.

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