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# The silver lining of supply chain complexity:
## *Building supply chain resilience and robustness through exploitation and exploration*


## Abstract

**Purpose –** The study aims to analyze whether the presence of supply chain complexity (SCC) influences firms to improve their supply chain (SC) resilience and SC robustness capability. We also examine an important paradox: if investing in both exploitation and exploration practices is conflicting or complementary in enabling SC resilience and SC robustness in the presence of SCC.

**Design/methodology/approach –** We used a survey-based approach to collect 242 useful responses from supply chain professionals of Pakistani firms, an important emerging economy context. The data were analyzed with covariance-based structural equation modelling to statistically validate our model.

**Findings –** The analysis reveals several key findings: (a) the presence of SCC has a direct, positive influence on SC resilience and SC robustness; (b) while exploitation practices only partially mediate the nexus between SCC and SC resilience, they fully mediate the relationship between SCC and SC robustness; (c) while exploration practices partially mediate the nexus between SCC and SC resilience, they do not mediate the relationship between SCC and SC robustness; and, (d) SCC has a significant influence on SC resilience and SC robustness sequentially through exploitation and exploration (i.e. one after the other).

**Practical Implications –** These findings help to reconcile the exploitation *versus* exploration paradox in cultivating SC resilience and SC robustness in the presence of SCC. The findings assist SC managers in determining how to deploy their limited resources most effectively to enhance SC resilience and SC robustness while facing SCC.

**Originality –** We devise and empirically validate a unique framework that demonstrates how the presence of SCC works as a stimulus to build SC resilience and SC robustness.


**Keywords:** Supply chain complexity, exploitation-exploration paradox, resilience, robustness.

## 1. Introduction

The current competitive context, characterized by increased globalization, higher levels of consumerism, and more diverse product portfolios, has made supply chains (SCs) more structurally diverse (Iftikhar et al, 2022; Ates et al., 2022) and SC partners more interdependent (Choi and Krause, 2006) than ever before. This level of supply chain complexity (SCC) also

means that disruptive events can have massive global consequences (Ali et al., 2022). The magnitude of disruption can be especially high in emerging economies where resources are constrained and striking a balance between SC exploitation (leveraging existing resources) and SC exploration (looking for novel solutions) is particularly challenging (Partanen et al., 2020; Ojha et al., 2018). Thus, practitioners find themselves enmeshed in a paradox of investing in what are considered by many to be two competing resources for mitigating the potential consequences of a disruption. In short, studying SC exploitation and exploration under conditions of SCC can help organizations better understand and manage their SCs, and to identify and pursue opportunities for resilience and robustness.

The increased complexity and resulting vulnerabilities of modern SCs have attracted scholarly attention aimed at building more robust and resilient SCs (Ali et al., 2022; Gu et al., 2021; Wieland, 2021). The existing literature discusses distinct aspects of complexity, along with their consequences (Ates et al., 2022). Some studies have examined the link between SCC and SC resilience, where a few have viewed SCC as a catalyst for improvement and recovery (Sheffi and Rice, 2005; Chowdhury et al., 2019; Iftikhar et al., 2022), while others have merely focused on the negative consequences of SCC (Bode and Wagner, 2015; Brandon-Jones et al., 2015) or on how to eliminate SCC (Aitken et al., 2016; Turner et al., 2018). Despite the strides forward that have been taken in recent years, there remains much to learn in this domain. In particular, the literature lacks empirical evidence on whether and how the presence of SCC influences SC resilience and SC robustness capabilities. That is, whether SCC could have a silver lining in that it can simultaneously improve SC resilience and robustness capabilities. We argue that, when inevitably exposed to SCC – characterized by a structurally diverse network and a dynamic business environment – firms adopt various strategies and actions to build a robust and resilient supply chain. This includes pursuing incremental improvements as

well as developing radical solutions that help in redirecting material flows and creating adapted structures (Chen et al., 2019; Zhao et al., 2019).

Despite growing attention on SCC research, it remains ill-understood how firms survive and build resilient and robust SCs while facing SCC. Although a few studies have explored the impact of SCC on SC resilience (Iftikhar et al., 2022; Wiedmer et al., 2021; Brandon Jones et al., 2015), the mechanisms through which SCC results in SC resilience and robustness are largely unclear. Similarly, Ates et al. (2022) conducted a meta-analysis and found that the existing SCC literature lacks a comprehensive understanding of the intervening mechanisms through which SCC improves or hinders organizational outcomes. Chowdhury and Quaddus (2017) also highlighted that the existing literature lacks insight into the processes and resources that promote competencies and capabilities during SC uncertainties and complexities. Likewise, Ivanov (2021) identified that studies focusing on reconfiguration, adaptation and resiliency are still scarce within structurally complicated supply networks or SCC. As such, it would be intriguing to determine how firms under SCC address their challenges and build SC resilience and robustness.

The existing literature has mainly discussed the structural strategies that could be employed to reduce the impact of a disruption and build resilience and robustness in complex SCs (Ali et al., 2017; Tang, 2006). Structural strategies include diversifying the supply base, redundancy in the supply and distribution network, having strategic reserves, and slack production capacities (Ali and Golgeci, 2019; Pettit et al., 2010). Limited research espoused the significance of SC exploitation and exploration practices in uncertain, complex and crisis environments (Osjyevskyy et al., 2020; Aslam et al., 2022). These practices stem from the organizational learning literature and are considered dynamic in nature, useful for adaptation and the firm's survival under SCC (Blome et al., 2013).

The realization of SC resilience and SC robustness would necessitate exploitation and exploration activities (Lee and Rha, 2016; Andriopoulos and Lewis, 2009). We posit that SC exploitation and exploration practices could be an intervening mechanism in the relationship between SCC and SC resilience and robustness. Exploitation involves the use of current skills and resources, enabling firms to develop incremental solutions, whereas exploration involves looking for external resources through collaboration with partners to develop radical and innovative solutions to address challenges under SCC (Ahammad et al., 2021). While exploration and exploitation practices are interrelated, SC managers often find themselves entangled in a paradox of investing in competing resources (Xiao et al., 2019; Aslam et al., 2022) – in our case, investing in exploration and exploitation activities to enhance SC resilience and SC robustness in the presence of SCC. According to the theory of paradox (TOP), businesses encounter a dilemma when trying to balance these opposing demands. Specifically, they utilize existing SC capabilities to address certain SCC challenges while exploring new SC solutions to address other SCC challenges. That is, companies must explore new opportunities and make use of existing capabilities to ensure success in the long run. However, these two practices are often in contrast to each other since exploration is oriented towards taking risks and experimenting with new ideas and pursuing novel solutions, while exploitation requires implementing and adopting incremental approaches with existing resources and capabilities (Ojha et al., 2018). This creates a paradox that firms must manage to achieve their business continuity and long-term survival.

The paradoxical tension between exploration and exploitation becomes particularly acute in emerging economies with limited resources to invest in addressing the threat of disruptions under SCC. It is not clear in the existing literature how firms manage these practices in this environment to build SC resilience and robustness. Therefore, to resolve the paradox we propose that firms must manage SC exploitation and exploration practices by considering a

sequential adoption approach. This involves initially focusing on exploitation practices to optimize existing resources and capabilities as a first line of defence. Then, once a firm has become proficient in this practice, it can shift towards exploration practices to develop new capabilities and opportunities to enable SC resilience and robustness in the face of SCC.

The significance of the topic and knowledge gaps in the literature motivates this study to examine whether and how SCC influences SC resilience and SC robustness, given the exploitation and exploration paradox. Investigating the interplay between SC exploitation and exploration in the presence of SCC allows for the analysis of existing business procedures and their effect on the relationship between SCC and both resilience and robustness. The following research questions (RQs) are posed:

RQ1: *What is the impact of SCC on SC resilience and SC robustness? And,*

RQ2: *Do SC exploitation and exploration mediate the relationship between SCC and SC resilience and robustness?*

By answering the above RQs, this study offers several new contributions. First, it recognizes SCC as an opportunity or trigger for enabling firms to develop SC resilience and SC robustness through exploration and exploitation activities. Second, we show that SC exploitation and exploration practices have distinctive and sequential mediation effects on the relationship between SCC and both SC resilience and robustness. Third, we help resolve the paradox of competing demands for resources that can be used to enhance exploration and exploitation activities. Finally, we contribute to the empirical literature on TOP by positioning the exploration and exploitation paradox at the interplay between SCC, SC resilience and SC robustness.

The remainder of this paper is organized as follows. Section 2 discusses the theoretical background before Section 3 presents the conceptual model and develops the research hypotheses. Section 4 discusses the research methodology followed by a discussion of the data

analysis and results in Section 5. Finally, in Section 6, we outline the theoretical and managerial implications, along with limitations and future research directions.

## 2. Theoretical background

### *2.1 Supply chain complexity (SCC)*

SCC is a multidimensional concept that refers to the various factors that make managing and coordinating a SC challenging due to associated risks and vulnerability (Wiedmer et al., 2021). These factors can include many suppliers and customers spanning different tiers, a wide range of products and services, a high degree of interdependence among supply chain partners, and a rapidly changing business environment.

The extant literature has classified SCC into different dimensions (Ates et al., 2022; Bode and Wagner, 2015) and explored its detrimental and beneficial effects (Bozarth et al., 2009; Giannoccaro et al., 2018; Iftikhar et al., 2022). In terms of classifying the SCC dimensions, Bozarth et al. (2009) categorized them into upstream, internal manufacturing and downstream dimensions grouped under structural and dynamic complexities. Similarly, Bode and Wagner (2015) categorized structural SCC into horizontal, vertical and spatial dimensions. A typical supply network is composed of many parts that interact in a complex manner (Simon, 1962). This refers to the notion that a supply network encompasses structural and dynamic aspects, representing a number and variety of elements in an SC structure and the interactions among these elements, respectively (Ates and Memis, 2022; Iftikhar et al., 2022). Structural complexity refers to the existence of various elements in the supply network, such as having multiple buyers and suppliers for each product or serving a large number of customers (Bozarth et al., 2009; Caridi et al., 2010). The literature has also defined structural complexity as static or detail complexity (Ates et al., 2022). Meanwhile, dynamic complexity stems from constant changes and uncertainties in the supply network, including demand fluctuation, supplier

delivery reliability and lead times (Ates et al., 2022). This type of complexity is also called operational complexity (Giannoccaro et al., 2018). In line with Chand et al., (2022), this study conceptualizes SCC construct on a formative scale, considering structural and dynamic dimensions as drivers of SCC. Thus, offering unique methodological and theoretical novelty. The extant literature on the nexus between SCC, SC resilience and SC robustness is scarce. Moreover, SCC literature mainly focuses on the structural aspect, neglecting the dynamic aspect (Birkie et al., 2017; Iftikhar et al., 2022). Recent research (Chand et al. 2022; Ates et al. 2022) has advocated investigating both structural and dynamic SCC simultaneously. Yet, the literature is silent on the simultaneous impact of structural and dynamic SCC on SC resilience and SC robustness, and the mechanisms underlying the relationship between these concepts.

### *2.2 Theory of paradox (TOP) and SC ambidexterity*

Paradoxes have been a central focus of management research for a long time, including the tensions between exploitation and exploration practices (Hargrave and Van de Ven, 2017). March (1991) highlighted that managing the paradoxical tensions between exploitation and exploration within the SC can be challenging. This is because, although both are important to a company's survival, they often compete for limited resources. Aslam et al. (2022) discussed how the TOP and the concept of ambidexterity, which considers both exploitation and exploration practices, can be used together to resolve paradoxical tensions and develop the ability to manage competing demands.

This study adopts both structural and dynamic complexities in order to conceptualize SCC as it is the paradoxical demands that arise from these two types of complexities that firms need to manage to achieve SC resilience and robustness. Certain features of SCC, such as relationship-building between suppliers and logistics providers, global sourcing between an extended network of supply bases, and managing dispersed customer bases may require the

efficient use of existing SC resources and capabilities, i.e., SC exploitation. At the same time, other features of SCC, such as uncertainties in deliveries and demand variability may require new SC solutions and radical innovation, i.e., SC exploration. This relies on an internal focus on existing resources and capabilities and an external focus on the resources and capabilities needed to develop innovative solutions (Syed et al., 2020). This creates paradoxical tensions as the two practices compete for limited organizational resources meaning an excessive focus on either exploitation or exploration could severely affect the other. Therefore, firms require both practices, exploitation and exploration, collectively referred to as SC ambidexterity, to address the challenges of SCC. Considering the underlying paradoxes in SCC, there is a notable lack of empirical evidence on the effectiveness of alternating between periods of exploitation and exploration to adapt and respond to changing conditions under complex environments.

The theory of paradox (TOP) has recently received scholarly attention in the extant SC literature (Zhang et al., 2021; Aslam et al., 2022; Matthews et al., 2016). It has helped explain how managers can engage or support strategies A and B to achieve organizational outcomes – in our case, resilience and robustness. SC managers quite often face paradoxes, i.e., contradictory yet interrelated elements, involving the reconciliation of competing demands whilst managing their SC operations (Xiao et al., 2019; Partanen et al., 2020). Applying TOP can offer critical insights into addressing interwoven challenges in supply network systems and can create new opportunities for businesses and SCs to grow (Zhang et al., 2021; Smith et al., 2017). Despite some early contributions to TOP, there is still much to learn about its influence on today's complex SCs. Therefore, TOP and SC ambidexterity can be used to understand how SC resilience and robustness can be achieved in the presence of SCC (Papachroni et al., 2015).

### *2.3 SC ambidexterity – exploitation and exploration practices*

Literature suggests that the two elements of SC ambidexterity, i.e. exploitation and exploration, necessitate different organizational designs and capabilities (O'Reilly and Tushman, 2013; Bustinza et al., 2020). SC exploitation focuses on short-term measurable targets while leveraging current resources, expertise, and technology to continuously improve operational efficiency (Adler et al., 2009). This allows for efficient decision-making and resource allocation, but it may also lead to inflexibility and a lack of agility in the face of disruptions or changes in the market. On the other hand, organizations that prioritize SC exploration tend to have more decentralized and flexible structures, with a culture that encourages experimentation and risk-taking (Ahammad et al., 2021). This enables them to be more adaptable and responsive to changes in the environment, but this may also come with higher costs and risks. The literature on the elements of SC ambidexterity (exploitation and exploration) is overwhelmingly discussed in the innovation domain, yet few studies have examined their role in the SCC domain (Lin et al., 2013). Studies have examined the importance of social capital in enabling ambidextrous capabilities (Aslam et al., 2022); the influence of network capabilities on SC ambidexterity (Partanen et al., 2020); and the role of big data analytics in untangling ambidextrous capabilities (Wamba et al., 2020). Yet, the roles of SC exploitation and exploration in achieving SC resilience and SC robustness under the conditions of SCC remain ill-understood. We, therefore, argue that, due to the multifaceted nature of resilience and robustness, the effectiveness of exploitation and exploration practices to achieving resilience and robustness may vary.

### *2.4 Supply chain resilience*

SC resilience is a multidisciplinary concept. Depending on the objective of the researcher, different conceptualizations exist in the extant literature, from static to dynamic SC resilience. The static conceptualization focuses on the ability of the SC to absorb a disturbance while

maintaining its core functionality (Giannoccaro and Iftikhar, 2020). In contrast, dynamic conceptualization refers to adapting the SC and reaching a new equilibrium position (Tukamuhabwa et al., 2015). In this research, we rely on the dynamic conceptualization of SC resilience, i.e. "*an adaptive capability that prepares supply chains for unexpected events and responds to and recovers from disruptions with connectedness and control"* (Ponomarov and Holocomb, 2009, p. 131). The adaptive role of resilience has the potential for competitive advantage as it focuses on reaching a new equilibrium and favourable position after a disruptive event (Giannoccaro and Iftikhar, 2020). For instance, governments throughout the world enforced strict COVID-19 lockdowns, extending the period of disruption and uncertainty and making it harder to achieve a pre-disruption stage in the immediate term (Hu et al., 2021). Furthermore, experts claimed that, following COVID-19, work and travel patterns throughout the world had shifted – these adaptations were first survival measures but are now likely to remain as part of the new normal (Hitt et al., 2020) meaning it is challenging to truly return to its pre-disruption state. This establishes that SC resilience is about recovering, adapting, and transforming to overcome obstacles and reap the rewards of diverse possibilities that are presented in a turbulent business environment (Wieland, 2021).

Firms also develop mechanisms that enable them to remain robust, i.e. to maintain their intended performance despite a disruption or series of disruptive events (Simchi-Levi et al., 2018). Both SC resilience and robustness are distinct concepts and are referred to as capabilities to effectively address the challenges of disruptive and complex environments (Kwak et al., 2018; Tang, 2006). According to Asbjørnslett (2008), robustness focuses on resisting and sustaining while resilience leans towards adapting and recovering capacities.

### *2.5 Supply chain robustness*

The concept of SC robustness focuses on the ability of a business to maintain its core operations and manage the impact of disruptions, whether internal or external (Vlajic et al., 2012). This includes implementing measures in advance (*ex-ante*) to mitigate risks and minimize their impact (Klibi et al., 2010). A robust SC can remain stable and effective in all future circumstances, allowing firms to buy more time to reconfigure their resources and develop effective risk mitigation strategies (Kwak et al., 2018; Wieland and Wallenburg, 2012).

The literature on SC robustness suggests that it is a proactive approach to dealing with turbulent conditions, allowing businesses to prepare for disruptions without the need for immediate changes (Durach et al., 2015; Iftikhar et al., 2021). Robustness implies a defensive capacity to maintain the stability and performance of a business, and it is often related to standard supply chain design decisions. Robust supply chains are immune to reasonable variations and recurrent events that have a low impact, thereby enabling them to maintain business continuity (Tang, 2006; Klibi et al., 2010). To develop SC robustness, businesses may need to implement measures such as incorporating redundancy and flexibility into their supply bases by maintaining substitute suppliers and strategic stocks (Tang, 2006). This can reduce vulnerability in the environment and allow for a more flexible network, reducing the frequency of risk reoccurrence. Firms that can scan their environment to identify sources of risks are in a better position to withstand the effects of disruption and maintain their projected performance (Ivanov and Sokolov, 2013.

Distinctively, SC robustness plays a major role initially by proactively building a structure and a design to minimize and/or eliminate a regular risk occurrence (Tang, 2006). In contrast, SC resilience is significant at a later stage to mitigate unexpected and/or subsequent disruptive events by showcasing its reactive nature – surviving, adapting and reacting (Ponomarov and Holcomb, 2009). Moreover, it should be noted that robust SCs are designed to withstand low-

impact and recurrent events while resilient SCs are able to deal with high-impact and low-probability disruptive events (Pettit et al., 2010).

## 3. Conceptual model and research hypotheses

### *3.1 Relationship between SCC, resilience, and robustness*

Global SC networks with diverse structures are vulnerable to a variety of risks, reducing their ability to deal with disruption (Birkie et al., 2017; Iftikhar et al., 2022). The complexity of the network, including the number of nodes and their interactions, determines the severity of disruption and presents challenges to the resilience of the SC (Giannoccaro and Iftikhar, 2020; Wiedmer et al., 2021). The interconnectedness of the nodes, including material, return, and transfer flows, can create interdependencies, which means that the impact of a disruptive event can be passed on to other nodes and affect the overall resilience of the supply chain.

The extant literature has discussed the positive role of SCC in building SC resilience (Craighead et al., 2007; Wiedmer et al., 2021; Iftikhar et al., 2022). The authors have discussed how having a variety of elements within the supply chain can enhance its ability to handle unexpected disruptions. This is due to the flexible nature of the structural concept of SCC. For example, having a wide supply base ensures a manufacturer has business continuity during a supply disruption as it can shift its orders to alternative suppliers through flexible sourcing or redundant suppliers (Sheffi and Rice, 2005; Chowdhury et al., 2019). Most research focuses on structural complexity in the SC resilience domain (Birkie et al., 2017; Chowdhury et al., 2019), omitting dynamic aspects of the SCC concept. Elements that contribute to the dynamic aspect of SCC include delivery complexity and demand volatility (Bozarth et al., 2009). To respond to demand volatility at short notice, firms rely on sourcing intermediaries to switch between supply sources (Masson et al., 2007). In addition, firms can display a high level of resilience by seeking flexibility from outside their existing network to address rapid changes

in demand (Chang and Lin, 2019). For example, multiple sourcing strategies can help to reduce the severity of an initial disruption. Overall, progressive firms in the wake of dynamic complexity and uncertainty evolve new structures and develop new capabilities and information-sharing mechanisms, such as by identifying alternative delivery routes, adjusting delivery schedules, developing a local supplier base, and exploring alternative raw material suppliers (Ali et al., 2022), to improve their responsiveness to operational disruptions.

The extant literature argues that SCC creates uncertainty within the network but also creates an opportunity for managers to restructure their supply networks (Choi et al., 2021). SC robustness is an essential capability for businesses so they can maintain their operations despite being in a crisis (El-Baz and Ruel, 2021). Under the conditions of SCC with greater vulnerabilities and uncertainty, firms seek redundancy in the supply base and develop slack capacities for production to remain robust (Tang, 2006). This shows that the presence of a diversified supply base (structural complexity) can play a pivotal role in the initial stage after a disruption because a well-designed supply and logistics network will minimize and/or eliminate regular risk occurrences (Kwak et al., 2018). This could incentivize firms towards SC robustness in order to remain competitive. In addition, to anticipate and withstand disruptions, firms invest in developing control towers and real-time monitoring and analytical tools (Vlachos, 2021; Iftikhar et al., 2022). These tools provide real-time information on production and inventory levels in the network, helping firms manage their dynamic complexities. Given this discussion, it is plausible that the presence of SCC can work as a catalyst for firms to develop resilience and robustness capabilities and maintain business operations in a turbulent business environment. Therefore:

*H1: The presence of supply chain complexity positively influences supply chain resilience*

*H2: The presence of supply chain complexity positively influences supply chain robustness*

### *3.2 The mediating influence of SC exploitation and exploration*

The paradoxical features of SCC trigger firms to practice SC ambidexterity, utilizing exploitation and exploration practices to handle conflicting demands (Aslam et al., 2022). We grounded our research in the TOP and ambidexterity, which suggests that firms can cultivate a SC ambidexterity capability by both exploring and exploiting their SC resources. This approach helps firms to manage the structural and dynamic complexities of their SC and achieve improved outcomes such as greater SC resilience and robustness.

The pursuit of SC exploitation and exploration can address the challenges of structural features of SCC and can enhance the resilience and robustness of SCs. For instance, SC exploitation practices allow firms to reconfigure their resources and seize opportunities from within the network to achieve flexibility benefits (Iborra et al., 2020), thereby improving a firm's ability to respond to different threats and disruptions, recover promptly and maintain performance (Iftikhar et al., 2021). In addition, when faced with an uncertain environment, firms adopt exploitative practices by developing standardized information formats among their supply and customer bases, consolidating their orders and shipments from multiple suppliers, and building relationships with key suppliers to reduce conflicts, improve recovery times and maintain stability (Gu et al., 2021; Lee and Rha, 2016). With an exploitation practice, firms also continuously scan and analyze their geographically-diverse network to identify potential disruptions, leverage their partner's expertise, and involve their suppliers at an early design stage to identify improvement opportunities proactively and design their supply network in such a way that it is conducive to SC robustness (Ivanov and Sokolov, 2013; Durach et al., 2015). Thus, under a diversified supply network representing structural complexity, the efficient utilization of existing resources and capabilities through exploitation could help firms reduce the effect of disruption and maintain both SC resilience and SC robustness capabilities.

Similarly, to address the challenges of the dynamic features of SCC, firms and their logistics partners can leverage integrated information technology (IT) systems to quickly share and access information (Rai and Tang, 2010). This strategic utilization of SC resources firms can improve the network visibility and thus its resilience and robustness (Brandon-Jones et al., 2014). By implementing integrated IT systems, firms gain real-time insights into their supply chain operations, enabling them to adjust and adapt their SC operations based on changing market conditions to resist and promptly respond to a disruption (Chen et al., 2014; Cheng and Lu, 2017). Companies that continuously learn and gather knowledge (exploitation) about potential risks and vulnerabilities in the presence of complex supply networks can take proactive measures to mitigate those risks. This can help an organization avoid costly disruptions and maintain the flow of goods and services, increasing the overall robustness of the SC (Norrman and Wieland, 2020). This signifies that SC exploitation practices allow firms to adjust, reorganize and prioritize their existing resources to better respond to market dynamics, minimize volatility, and move towards a resilient and robust SC. Based on this discussion, we devise the following hypothesis:

*H3a: The presence of SCC positively influences SC resilience through exploitation activities*

*H3b: The presence of SCC positively influences SC robustness through exploitation activities*

SC exploration practices are oriented towards discovering new knowledge, opportunities and solutions through experimentation and innovation (Lee et al., 2015). Exploration encourages SC partnering firms to integrate within their extensive network (supplier side and customer side), managing structural complexities, to enable deep information sharing that generates new knowledge and ideas (Im and Rai, 2008). The explorative use of expertise and information improves a firm's readiness and responsiveness to potential disruptions (Ahammad et al., 2021; Ali et al., 2022). The innovative applications, resulting

from SC exploratory practices, materialize through technologically-advanced infrastructure and equipment investments (Wagner and Bode, 2008), thus facilitating SCs in enhancing resilience and robustness (Kwak et al., 2018). Furthermore, the explorative use of new technologies strengthens inter-firm collaboration and streamlines structural complexity (Rai et al., 2006; Iftikhar et al., 2022). In global SCs, with an abundance of potential suppliers in multiple industries, adopting big data analytics could facilitate the supplier selection process, blockchain technology could improve transparency, and drones could assure delivery reliability, enabling the optimal design of the SC's structure to ensure its resilience and robustness (Iftikhar et al., 2021; Azmat and Thanou, 2023; El-Baz and Ruel, 2021). Certain industries are also under constant pressure to achieve their goals of transparency and traceability, such as by developing new SC solutions and radical approaches, and by adopting newer innovative technologies that assist in monitoring product history, tracking the origins of goods, and improving transparency (Tao et al., 2020; Ali et al., 2021). Thus, exploratory practices help firms to improve the supply network's visibility and resilience during a disruptive event. Moreover, an extensive upstream and downstream network also generates a greater volume and variety of data. For example, innovative SC approaches and solutions can be used experimentally to determine ideal inventory levels during volatile demand periods and in uncertain environments, managing the dynamic complexities, thereby enhancing a firm's capacity to ensure business continuity (Tarafdar and Qrunfleh, 2017; Jabbarzadeh et al., 2017). This signifies that SC exploration practices allow firms to reduce the impact of a disruption and enable both resilience and robustness by exploring out-of-the-box ideas and solutions in the presence of SCC. Therefore, we propose the following hypothesis:

*H4a: The presence of SCC positively influences SC resilience through exploration activities*

*H4b: The presence of SCC positively influences SC robustness through exploration activities*

We explore the possibility of serial mediation by examining whether the influence of SCC on resilience and robustness is mediated jointly and sequentially by exploitation and exploration activities, in addition to the distinct mediating linkages of SC exploitation and exploration activities on the relationship between SCC and both resilience and robustness. This option extends beyond separate mediating linkages for exploitation and exploration activities. Furthermore, path dependence between the exploitation and exploration constructs is also investigated.

To address the paradoxical demands of SCC, we argue that the ambidexterity elements, i.e. exploitation and exploration activities, could transition sequentially, one after the other (O'Reilly and Tushman, 2013; Papachroni et al., 2015). To develop SC resilience and robustness, firms develop competencies and mechanisms that could mitigate disruptive events. Under SCC, with its greater interconnectedness and associated uncertainty, firms must utilize their existing skills and resources (exploitation) to resist and withstand disruption as a first line of defence. Once they are proficient in their internal capabilities, they can pursue novel SC solutions (exploration). As exploration practices require more time and investment to form the foundations before firms can capitalize on them (Azadegan and Dooley, 2010; Osjyevskyy et al., 2020), their beneficial effect on SC resilience and SC robustness would be less if pursued earlier than exploitation (Gu et al., 2021). Therefore, it is argued that firms would be better off sequentially moving from exploitation to exploration to improve their resilience and robustness under the conditions of SCC. By initially focusing on exploitation – to optimize existing capabilities and relationships before exploring new SC solutions, ideas and innovative approaches to adapt to changing circumstances – a firm can effectively manage the trade-offs between efficiency and adaptability.

In the existing literature, empirical research on sequential switching between SC ambidexterity elements, at the nexus of SCC and both SC resilience and SC robustness, is at a

nascent stage of development. This can leave practitioners unsupported when allocating their limited resources. This discussion leads to the following:

*H5a: The presence of SCC positively influences SC resilience sequentially through exploitation and exploration activities (i.e. one after the other).*

*H5b: The presence of SCC positively influences SC robustness sequentially through exploitation and exploration activities (i.e. one after the other).*

## 4. Research method

This study utilizes a positivist paradigm, which relies on observable and quantifiable measures (Zikmund, Babin et al. 2013) to achieve an objective approach to data collection. The research approach is deductive and quantitative, using a survey instrument as the primary data collection method, following widely accepted procedures to structure the survey questionnaire and conduct the sampling (Dillman 2000). That is, a simple random sampling method was employed, which ensures that all participants have an equal chance of being selected and that they are representative of the whole population, thereby reducing selection bias. The unit of analysis is at the firm level within an emerging economy, Pakistan, representing an important yet under-researched context with the potential to offer novel insights to the SCC literature. Pakistan has extended SCs that trade parts and products with many other nations at an annual value of $25-30 billion (Pakistan Economic Survey, 2021). The country is particularly well known for the production and exportation of world-class textiles, leather, surgical equipment and sporting goods (Pakistan Economic Survey, 2021). Therefore, any disruptions to these operations will have a domino effect that disturbs the downstream parts of their SCs all around the world.

### *4.1 Measures for the construct*

The research framework for this study is drawn from existing literature and uses validated item scales on a 5-point Likert scale from strongly disagree (1) to strongly agree (5). The constructs and related items can be found in Table 1. In the following section, we provide details of each empirical construct used in this study.

The construct *supply chain complexity* was measured as a higher-order formative construct adapting from Ates et al. (2022), Chowdhury et al. (2019), and Bozarth et al. (2009). Within this construct, we used structural and dynamic dimensions as lower-order constructs. We used these two dimensions to obtain a complete and holistic understanding of SCC. The measures of SCC were developed collectively by considering its two dominant dimensions.

Meanwhile, the mediating variables, *SC exploitation* and *SC exploration,* each used 4 items adapted from Partanen et al. (2020) and Kristal et al. (2010). The dependent variable, *SC resilience,* was measured using 5 items adapted from Ambulkar et al. (2015) and Gölgeci and Kuivalainen (2020), and *SC robustness* used 4 items which were adapted from Kwak et al. (2018) and Wieland and Wallenburg (2012).

### *4.2 Pre-testing the survey instrument*

Most of the items were validated through previous research, while content validity and reliability tests were conducted on the adapted measurement items. Four industry executives and two academics were consulted for feedback on the items and constructs, and improvements were made based on their extensive practical and theoretical knowledge. The reliability of the measurement items was evaluated, with all constructs having a Cronbach's alpha value higher than 0.7 (Hair, 2009). The questionnaire was pre-tested with 50 industry respondents and improvements were incorporated to create the final version, with pre-test participants excluded from the main survey and analysis.

### *4.3 Main survey*

The data were collected from senior managers of firms in manufacturing SCs. A structured questionnaire was distributed to 1,200 respondents. After two email reminders, 242 useful responses were received, with a response rate of 20.2%. The demographic information demonstrates the heterogeneity of our sample (see Table 1). Since the data were gathered from multiple manufacturing industries, we conducted a chi-square test to compare the distribution of industry sectors between the real situation and our sample. The analysis returned a non-significant ($p > 0.05$) outcome thereby suggesting no difference between the real situation and our sample.

*Non-response bias* was tested following the guidelines outlined in Armstrong and Overton (1977), as adopted in previous survey-based studies in the field (e.g. Chowdhury et al. 2019; Ko et al. 2021). A comparison between early and late respondents was made based on the four variables of the model (Figure 1). The independent sample t-test showed no significant differences ($p > 0.05$) between early and late respondents, meaning non-response bias was not a concern in this study.

========== Insert Table 1 ==========

## 5. Data Analysis and Results

### *5.1 Measurement reliability and validity*

We assessed the reliability and validity of the measures using confirmatory factor analysis (CFA). The results indicated that our model fit indices are within acceptable limits (Bentler and Chou 1987, Hair et al. 1998, Hair 2009): CMIN = 2.38, CFI = 0.94, GFI = 0.93, AGFI = 0.91, NFI = 0.92, and RMSEA = 0.034. Further, our scales presented sufficient psychometric properties (see Table 2). The values for average variance extracted (AVE) and composite reliability crossed the threshold values of 0.50 and 0.60, respectively. Meanwhile, the square

root of the AVE of each construct was higher than its correlation (Table 3) with all other constructs (Fornell and Larcker 1981). The heterotrait-monotrait ratio (HTMT) method was employed in our analysis, and the results revealed that the HTMT values for the constructs were significantly below the threshold of 0.85 recommended by Henseler et al. (2015), as seen in Table 3. This suggests that the discriminant validity is established. Further, the factor loading of all individual items was higher than 0.50 and all items were loaded onto their respective latent variables, thereby confirming convergent validity. The Cronbach's Alpha value of all constructs surpassed the recommended value of 0.70 (Nunnally 1978, Hair, 2009). Finally, the test of variance inflation factors (VIF) was much lower than the threshold value of 10 (highest VIF = 2.312), suggesting no issue with multicollinearity.

========== Insert Table 2 ==========

To control for common method bias (CMB), we undertook numerous *ex-ante* and *ex-post* remedies (Podsakoff, MacKenzie et al. 2003). The *ex-ante* remedies involved procedural measures such as ensuring measurement items were drawn from established scales, guaranteeing respondent anonymity, dividing the questionnaire into various sections, and separating the independent and dependent variables (Wamba et al., 2020; Fawcett et al., 2014). *Ex-post* remedies involved some common statistical analyses. First, it is believed that reverse-worded items break the pattern established by CMB (Nunnally et al. 1978, Paulhus 1991, Jordan and Troth 2020). We, therefore, used two reverse-worded items: *We do not face demand variation in our products or desire different products by our customers; Our supply chain network cannot remain effective nor sustained during internal/external disruptions*. The analysis indicated that reverse-worded items were negatively correlated with other items. Second, we conducted Harman's (1976) single-factor test, where five factors with an eigenvalue above 1 were extracted and the average variance extracted by any individual

construct was much lower than the cut-off value of 50%. Third, all observed variables were loaded to a common latent factor (CLF). A comparison between the standardized regression weight of the model, both with and without CLF, suggested a non-significant difference ($p > 0.05$). These statistics confirm that CMB is not likely to be a concern in this study.

========== Insert Table 3 ==========

*5.2 Hypotheses testing: Structural model analysis*

We used SPSS with Amos 28 to test the direct and indirect relationships in our model. First, we created a full model using Amos graphics and tested the overall model fit. The results indicated that our model fit indices are within acceptable limits (Bentler and Chou 1987, Hair, Anderson et al. 1998, Hair 2009): CMIN = 2.41, CFI = 0.93, GFI = 0.95, AGFI = 0.89, NFI = 0.94, and RMSEA = 0.036.

========== Insert Figure 1 ==========

Next, we tested the direct and indirect (mediation) effects (see Table 4) following Baron and Kenny's (1986) procedure, which has been used in several recent studies (e.g. Li & Huang, 2012; Miemczyk & Luzzini, 2019; Eryarsoy et al., 2022). The procedure implies the following four conditions for the mediation test:

1. Independent and dependent variables should be correlated (Baron and Kenny 1986). Consistent with this, our analysis suggested a significant positive relationship between SCC and SC resilience ($\beta$=.196, $p$ = .013) and SC robustness ($\beta$=.219, $p$ = .017), thus H1 and H2 were supported.
2. The independent variable should have a significant relationship with the mediators (Baron and Kenny 1986). Correspondingly, our analysis indicated that SCC, as an independent

variable, has a significant relationship with exploitation (β=.205, p = .015) and exploration (β =.215, p = .021), the mediators.

3. The mediator should have a significant relationship with the dependent variables (Baron and Kenny 1986). In congruence, we found a significant relationship between SC resilience and exploitation (β =.2785, p = .006) as well as SC resilience and exploration (β=.219, p = .025). Likewise, the relationships between SC robustness and both exploitation (β=.329, p = .002) and exploration (β=.195, p = 0.041) were also found to be significant.
4. With the inclusion of the mediator, if the impact of the independent variable on the dependent variable changes from significant to insignificant or *vice versa*, a full mediation is established. However, with the inclusion of the mediator, if the impact of the independent variable on the dependent variable decreases then a partial mediation is established (Baron and Kenny 1986). Addressing this condition, our analysis establishes the following outcomes:
    i. SCC has greater influence on SC resilience with the inclusion of exploitation as a mediator (.291** p < .006), thereby indicating a partial mediation. As such, H3a was not supported.
    ii. The influence of SCC on SC robustness changes from significant to insignificant with the inclusion of exploitation as a mediator (.117 p < .079), indicating that exploitation fully mediates the relationship between SCC and SC robustness. As such, H3b was supported.
    iii. SCC has greater influence on SC resilience with the inclusion of exploration as a mediator (.315**, p < .003) – the significance level increases from 0.05 to 0.01 – indicating a partial mediation. Thus, H4a was supported.
    iv. SCC did not indicate a visible change in SC robustness with the inclusion of exploration as a mediator (.213* p < .019), thus suggesting that SC exploration does

not mediate the nexus between SCC and SC robustness. As such, H4b was not supported.

v. The effect of the presence of SCC on SC resilience changes from significant to insignificant with the inclusion of both exploitation and exploration as mediators (.103 $p < .089$), thus indicating that exploitation and exploration together (one after another) fully mediate the nexus between SCC and SC resilience. As such, H5a was supported.

vi. The influence of the presence of SCC on SC robustness changes from significant to insignificant with the sequential inclusion of both exploitation and exploration (.113 $p < 0.87$), thus indicating that exploitation and exploration together (one after another) fully mediate the nexus between SCC and SC resilience. As such, H5b was supported. The findings thus unveil a positive outcome that exposure to SCC drives SC ambidexterity elements in sequential order from exploitation to exploration for both resilience and robustness.

### *5.3 Control variables*

The dataset exhibited variation in terms of the level of experience and gender of respondents and the size and industry type of organizations. These characteristics could potentially confound the primary results in our model; therefore, we applied measures to control for these variables in our analysis. We created dummy variables for the following: experience (1 = 3-5 years, 2 = 6-8 years, 3 = 9-11 years, 4 = more than 11 years); firm size (1 = below 500 employees, 2 = 500-1000 employees, 3 = more than 1000 employees); gender (1 = male, 2 = female); and industry type (1 = food & beverages, 2 = apparel and textile, 3 = automotive, 4 = construction, 5 = consumer goods, 6 = consumer electronics, 7 = shipping and logistics, 8 = pharmaceuticals, 9 = banking, hospitality, and consulting, 10 = energy and utility, 11 = others).

We then regressed the dummy variables on the dependent variable. The results were non-significant ($p > 0.05$) for all control variables, confirming that these variables have no confounding effect on the main relationships (hypotheses) in our model.

========== Insert Table 4 ==========

## 6. Discussion and conclusions

The unprecedented events and resulting disruptions of recent times have presented looming challenges to organizations embedded in structurally varied, diverse and interdependent supply networks. For instance, the prolonged COVID-19 containment measures and the conflict between Russia and Ukraine have put the resilience and robustness of global SCs to the test. Against this backdrop, there is substantial interest from scholars in understanding the best approach for enabling SC resilience and SC robustness in globalized and complex SCs. Firms either adopt SC exploitation, by extending and utilizing available resources and capabilities, or SC exploration, by developing new innovative solutions. We have explored the sequential interplay between exploitation and exploration practices in this context. Although researchers recently attempted to bridge the gap, a significant part of the extant literature on SCC, SC resilience and SC robustness is conceptual only and lacks empirical support (Iftikhar et al., 2022). It has therefore been challenging to adequately evaluate the risks and effectiveness of various approaches for recovering from disruptions and maintaining business continuity. Our study offers a nuanced perspective on how the presence of SCC positively triggers firms into developing SC resilience and SC robustness capabilities with implications for theory and practice.

### *6.1 Theoretical implications*

Our study makes several significant contributions to the literature on SCC, SC resilience, SC robustness, and SC ambidexterity. First, an important contribution of this study is the understanding of how organizations can manage the tensions between exploiting existing resources and capabilities and exploring new opportunities, which is a key aspect of organizational strategy. We utilize TOP and ambidexterity to address this knowledge gap and identify the paradoxical tensions of SCC. We argue that firms manage the underlying paradoxes between structural and dynamic complexities and address their challenges by pursuing both exploitation and exploration practices sequentially to enable SC resilience and robustness.

Second, prior research has a limited understanding of the nexus between SCC, SC resilience and SC robustness (Wiedmer et al., 2021); however, SCC has been conceptualized from a structural perspective only, providing a unidimensional focus. We contribute to this domain of research by studying both structural and dynamic aspects of SCC, thereby providing a broader perspective. Our argument that SCC lends support to SC resilience and SC robustness (*H1 – H2*) resonates with past scholarship on how firms that have diversified their supply bases and dispersed their production facilities across multiple countries can recover promptly to maintain business continuity (Matous and Todo, 2017). To avoid vulnerabilities that arise due to SCC, firms develop integrative and collaborative capabilities, identify alternative pathways, such as investments in strengthening their information-sharing mechanisms, and seek flexibility outside their extant network (Durach et al., 2015; Vlachos, 2021). This helps to withstand and recover from a disruption despite operating in a turbulent business environment (Ali et al., 2022).

Third, we have examined the individual roles of SC exploitation and SC exploration practices for achieving SC resilience and SC robustness. Scholars have debated the paradoxical demands of achieving and developing resilience and robustness capabilities (Aslam et al.,

2022; Paul and Chowdhury, 2020). We settle this debate by empirically validating for the first time how SC resilience and SC robustness can be achieved. Our study into SC exploitation practices suggests that exploitation acts as a mediator for both SC resilience and SC robustness capabilities in the presence of SCC (*H3a – H3b)*. We have shown that businesses that focus on SC exploitation strategies, such as by utilizing their internal resources and expertise more effectively than their competitors, are better equipped to swiftly reorganize their resources and develop stronger competencies within their supply chain processes, ultimately leading to an increase in SC resilience and robustness capabilities (Iftikhar et al., 2021; Lee and Rha, 2016). For example, in February 2020, during the COVID-19 pandemic, one of Samsung's Korean production sites, close to the country's COVID epicentre city, Daegu, stopped producing smartphones for several days due to illness among its workers. In response, Samsung swiftly moved its manufacturing operations to another site in Vietnam (Song, 2020). This demonstrates how an SC exploitation capability enables a company to efficiently leverage its resources, technology and expertise to respond quickly to disruptions (resilience), withstand them (robustness) and maintain business continuity despite being exposed to the challenges of SCC.

Fourth, we add to the literature on the role of SC exploration practices. These practices act as a mediator in the presence of SCC for achieving SC resilience but do not act in the same way for SC robustness (*H4a – H4b*). This is because, for SC resilience, firms either return to normal operations or adapt towards a new equilibrium position over an acceptable period after experiencing a disruption (Brandon-Jones et al., 2014) and perhaps deploy both exploitation and exploration activities. This suggests that firms may experiment with mitigation and recovery strategies under the conditions of SCC in a post-disruption period. However, for SC robustness (i.e. withstanding a disruption), which plays a significant role at an initial stage after a disruption, firms require an immediate response to maintain operations, which is likely to build upon the exploitation of existing resources, as building SC robustness requires a different

approach (Durach et al., 2015; Kwak et al., 2018). Our argument is in line with the extant literature; for example, Partanen et al. (2020) noted that SC exploratory practices that seek novel solutions require time and effort, and involve financial investment to capitalize on any opportunities, thus the chances of quickly developing a SC robustness capability in the presence of SCC is reduced. Therefore, it would not be a viable strategy to enhance SC robustness by experimenting with novel SC solutions and undertaking risky projects, as the immediate response and results would be uncertain.

Fifth, this study has also applied the sequential adoption of SC ambidexterity elements (one after another) to the nexus between SCC and both SC resilience and SC robustness (*H5a – H5b*). Interestingly, it has emerged as a full mediator, sequentially adopting SC exploitation first and then SC exploration practices. The literature lacks empirical insights into whether and how the presence of SCC drives SC ambidexterity elements to improve resilience and robustness. We posit that as SCC is an unavoidable reality, it would trigger the implementation of SC ambidexterity elements as a means of coping with it. Our mediation analysis confirms that SC ambidexterity elements are a sequential process and that firms must first become proficient at capitalizing on their existing SC resources and capabilities, allowing them to respond, recover and survive under the structural and dynamic nature of SCC. That is, by first being proficient in SC exploitation, firms can be ready with the first line of defence to withstand disruption. They can then subsequently leverage SC exploration practices to create innovative responses to upcoming challenges. This understanding not only provides support to the claims made about the multidimensional concept of SCC (Chand et al., 2022), but it also contributes to the debate on how firms should address and manage the challenges of SCC (Ates et al., 2022).

### *6.2 Managerial implications*

Our study offers several practical implications for managers of complex SCs seeking to develop more resilient and robust operations in a turbulent business environment. First, since SCC is inevitable in today's globalized business world, managers should consider SCC to be an opportunity and develop SC resilience and SC robustness within their supply chain network to withstand disruptions and/or recover promptly to improve their competitive position.

Second, our study informs managers of the approaches that lead to the instigation of SC resilience and SC robustness when facing SCC. Specifically, our findings guide practitioners towards the development of exploration and exploitation practices when facing SCC. Our analysis suggests that SC exploration practices alone would not lend support to SC robustness in the same way as they would to SC resilience. This reflects the emerging economy context of the study where firms often have a more severe budget and resource constraints, meaning investments in experimenting with novel SC solutions would be a risk to their ability to resist and withstand a disruption.

Finally, firms must also consider that SC exploitation has a significant role to play in achieving SC resilience and SC robustness capabilities under the conditions of SCC. Firms could utilize SC capabilities from within their existing network, such as by building integrated relationships with their suppliers and customers or by developing network alliances, so that more efficient actions can be taken. In addition, firms could leverage SC explorative practices to withstand a disruption if they have already become proficient at using existing SC resources and capabilities. This implies that the beneficial effects of SC exploratory practices on SC robustness depend on the efficient utilization of a firm's existing resource base. In sum, we argue that firms can achieve SC resilience and SC robustness, in the presence of SCC, when they make a combined investment in both exploitation and exploration capabilities.

### *6.3 Limitations and future research directions*

This study has been conducted in the context of manufacturing and from a developing country perspective. Caution must therefore be taken when extrapolating the findings. We believe the findings may benefit manufacturing industries operating in a similar socio-economic context to Pakistan but suggest future research replicates our empirical model for manufacturing in other socio-economic contexts to gauge the differences. Such work could also enable multi-country or comparative studies, even if single-country data is more common in many high-quality journals (Chand et al., 2022; Ali et al., 2022).

Meanwhile, we consider SCC to be a higher-order construct that incorporates structural and dynamic complexity. Future research could separately regress each dimension (structural and dynamic) on exploration and exploitation to observe the difference(s), if any. With an increasing focus on digital transformation (Ali *et al*., 2021; Iftikhar et al., 2022), future research could also observe the intervening influence of technologies on the linkages established in our model. Another fruitful avenue for future research would be to test the influence of leadership style on the realization of exploitation and exploration capabilities in the presence of SCC. Finally, SCC, SC resilience and SC robustness are dynamic measures and therefore we suggest undertaking engaged action and longitudinal research in the future to examine transformative changes as they happen.

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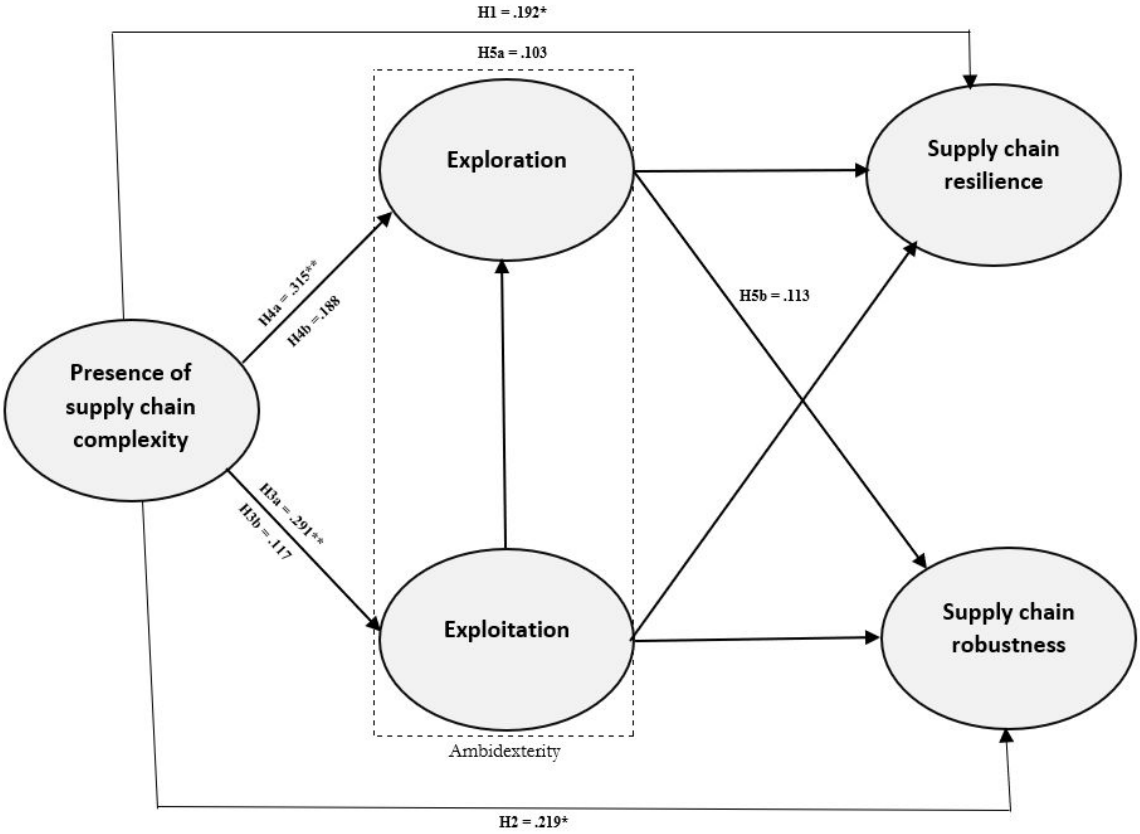


**Figure 1**. Statistically validated model and associated hypotheses

**Table 1.** Demographic profile of the respondents

| Dimension | Category | Number | Percentage |
|---|---|---|---|
| **Age** | 25 - 34 | 65 | 27% |
| | 35 - 44 | 108 | 45% |
| | 45 - 54 | 42 | 17% |
| | Over 55 | 27 | 11% |
| **Gender** | Female | 13 | 5% |
| | Male | 224 | 93% |
| | Prefer not to say | 5 | 2% |
| **Work Experience (years)** | 3 - 5 | 47 | 19% |
| | 6 - 8 | 43 | 18% |
| | 9 - 11 | 25 | 10% |
| | More than 11 | 127 | 52% |
| **Firm size** | 500 - 1000 employees | 66 | 27% |
| | Below 500 employees | 98 | 40% |
| | More than 1000 employees | 78 | 32% |
| **Annual Sales (Million PKR)** | 0 - 1000 | 59 | 24% |
| | 1001 - 2000 | 41 | 17% |
| | 2001 - 3000 | 53 | 22% |
| | > 3001 | 89 | 37% |
| **Managerial Designation** | Manager/Senior Manager | 163 | 67% |
| | General Manager | 28 | 12% |
| | Director | 20 | 8% |
| | CEO/Owner | 20 | 8% |
| | Assistant Manager | 11 | 5% |
| **Industry** | Food and Beverages | 9 | 4% |
| | Apparel and textile | 40 | 17% |
| | Automotive | 31 | 13% |
| | Construction | 8 | 3% |
| | Consumer Goods | 59 | 24% |
| | Consumer Electronics | 19 | 8% |
| | Shipping and Logistics | 5 | 2% |
| | Pharmaceuticals | 30 | 12% |
| | Banking, Hospitality and Consulting | 12 | 5% |
| | Energy and Utility | 14 | 6% |
| | Others | 15 | 6% |

**Table 2.** Construct reliability and validity

| Construct | Items | Factor loading | Mean | S.D | α | AVE | CR |
|---|---|---|---|---|---|---|---|
| **Supply chain complexity (SCC)** | We have multiple buyers for each product | .683 | 4.15 | 0.66 | 0.85 | 0.65 | 0.82 |
| | We have multiple suppliers for each material/part | .720 | | | | | |
| | Our suppliers are located in diverse geographical areas | .676 | | | | | |
| | Our firm/plant serves a large number of customers | .725 | | | | | |
| | We have multiple production or logistics facilities in different areas | .705 | | | | | |
| | We can depend on on-time delivery from suppliers in this supply chain | .759 | | | | | |
| | Our company strives to shorten supplier lead times to avoid inventory and stockouts | .566 | | | | | |
| | We often face demand variation in our products | .775 | | | | | |
| | Our customers desire different products with multiple features | .799 | | | | | |
| **Exploitation (Exploit)** | In order to stay competitive, our supply chain managers focus on reducing operational redundancies in our existing processes | .876 | 4.16 | 0.67 | 0.74 | 0.63 | 0.71 |
| | Leveraging our current supply chain technologies is important to our firm's strategy | .761 | | | | | |
| | In order to stay competitive, our supply chain managers focus on improving our existing technologies | .721 | | | | | |
| | Our managers focus on developing stronger competencies in our existing supply chain processes | .754 | | | | | |
| **Exploration (Explor)** | We proactively pursue new supply chain solutions | .727 | 4.2 | 0.77 | 0.79 | 0.61 | 0.76 |
| | We continually experiment to find new solutions that will improve our supply chain | .791 | | | | | |
| | To improve our supply chain, we continually explore to identify new opportunities | .792 | | | | | |
| | We are constantly seeking novel approaches to solving supply chain problems | .769 | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Supply Chain Resilience (SCR)** | We are able to adequately respond to unexpected disruptions by quickly restoring our product flow | .660 | 4.04 | 0.81 | 0.87 | 0.67 | 0.79 |
| | We are well prepared to deal with the financial outcomes of potential supply chain disruptions | .742 | | | | | |
| | We are able to provide a quick response to a supply chain disruption | .719 | | | | | |
| | We are able to adapt to a supply chain disruption easily | .772 | | | | | |
| | We are able to cope with changes brought about by a supply chain disruption | .723 | | | | | |
| **Supply Chain Robustness (Robst)** | Our supply chain and logistics networks can remain effective and be sustained even when internal/external disruptions occur | .788 | 3.89 | 0.83 | 0.85 | 0.66 | 0.74 |
| | Our supply chain and logistics networks can avoid or minimize risk occurrences by anticipating and preparing for them | .799 | | | | | |
| | Our supply chain and logistics networks can absorb a significant level of negative impacts from recurrent risks. | .743 | | | | | |
| | Our supply chain and logistics networks have sufficient time to consider the most effective reactions | .665 | | | | | |

**Table 3.** Discriminant validity coefficients[a]

| Construct | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. SCC | ***.81*** | 0.69 | 0.52 | 0.68 | 0.55 |
| 2. Exploit | 0.45 | ***.79*** | 0.78 | 0.64 | 0.66 |
| 3. Explor | 0.41 | 0.50 | ***.78*** | 0.50 | 0.58 |
| 4. SCR | 0.59 | 0.45 | 0.40 | ***.82*** | 0.76 |
| 5. Robst | 0.48 | 0.45 | 0.46 | .64 | ***.81*** |

[a] Diagonal values are the square root of AVE; below the diagonal are the inter-construct correlation; and, above the diagonal are the HTMT values.

**Table 4.** Results of the structural model

| Hypotheses | Direct without mediator β(p-value) | Direct with mediator β(p-value) | Results |
|---|---|---|---|
| SCC->Exploit->SCR | .192* (.031) | .291** (.006) | Partial mediation |
| SCC->Explor->SCR | .192* (.031) | .315** (.003) | Partial mediation |
| SCC-> Exploit -> Explor ->SCR | .192* (.031) | .103 (.089) | Full mediation |
| SCC->Exploit->Robst | .219* (.017) | .117 (.079) | Full mediation |
| SCC->Explor->Robst | .219* (.017) | .213* (.019) | No mediation |
| SCC-> Exploit -> Explor ->Robst | .219* (.017) | .113 (0.87) | Full mediation |

**Note**: *$p$<0.05, **$p$<0.01, ***$p$<0.001
SCC = Supply chain complexity, SCR = Resilience, Robst = Robustness, Explor = Exploration, Exploit = Exploitation