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Enhancing Supply Chain Risk Management Capabilities Through Product and Process Innovation

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Abstract
This study examines the influence of supply chain innovation practices, specifically product innovation and process innovation, on supply chain risk management (SCRM) capabilities and performance. Grounded in Dynamic Capabilities Theory, the research argues that innovation enables firms to identify risks, capitalize on emerging opportunities, and reconfigure resources effectively in uncertain business environments. Using a quantitative explanatory approach, data were collected from 276 professionals working in export-oriented manufacturing firms in Pakistan and analyzed through Partial Least Squares Structural Equation Modeling (PLS-SEM). The findings reveal that both product and process innovation significantly strengthen supply chain resilience and robustness. Furthermore, resilience has a significant positive impact on SCRM performance, whereas robustness does not show a statistically significant effect. These results highlight the importance of integrating innovation into supply chain activities to enhance risk management capabilities, improve responsiveness to disruptions, and support faster recovery in dynamic and challenging environments. The study contributes to the supply chain management literature by providing empirical evidence on the role of innovation in developing effective SCRM capabilities and improving organizational performance.

Keywords: Innovation Capability; Supply Chain Risk Management; Supply Chain Resilience; Process Innovation; Product Innovation.

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1. Introduction

The increasing complexity of global supply chains has exposed organizations to a wide range of disruptions that threaten operational continuity and business performance. In recent years, supply chains have been challenged by numerous unforeseen events, including natural disasters, global health emergencies, geopolitical tensions, armed conflicts, and terrorist incidents (Zheng et al., 2025; Babu & Yadav, 2023; El Baz & Ruel, 2021; Araz et al., 2020). These disruptions have generated significant economic consequences and adversely affected the performance of industries worldwide (Ruel & El Baz, 2023; Ivanov & Dolgui, 2020). Consequently, firms are increasingly required to develop capabilities that enable them to anticipate disruptions, respond effectively to crises, and recover rapidly from unexpected events. Building adaptive and resilient organizational capabilities has therefore become a strategic priority for maintaining competitiveness in volatile business environments (Hurtado-Palomino et al., 2022).

The contemporary business landscape is characterized by accelerated technological change, digital transformation, and the emergence of virtual business ecosystems. These developments have fundamentally altered the way organizations design and manage their supply chain operations (Foli et al., 2024; Sodhi & Tang, 2021). Recent studies suggest that organizations equipped with adaptive innovation mechanisms are more capable of maintaining operational continuity and recovering from disruptions than those relying on traditional management approaches (Araz et al., 2020; Huma et al., 2024). As a result, understanding how firms can strengthen their supply chain capabilities in response to increasing uncertainty has become an important research and managerial concern. In this context, supply chain risk management (SCRM) has emerged as a critical approach for addressing the growing frequency and severity of supply chain disruptions.

Innovation-oriented supply chains are generally better positioned to cope with uncertainty because they are more likely to adopt advanced technologies, establish stronger collaboration with partners, and develop flexible operational processes (Tidd, 2010; Afraz et al., 2021). Beyond external shocks, supply chains must also confront internal challenges such as economic instability, fluctuating demand, technological changes, and infrastructure limitations. These challenges are particularly pronounced in developing economies where export dependence and inadequate infrastructure increase vulnerability to supply chain risks (Huma & Siddiqui, 2025; Ahmed et al., 2023; Afraz et al., 2021). Consequently, innovation has become an essential strategic resource for improving supply chain adaptability and strengthening risk management capabilities.

The literature has long recognized innovation as a key driver of organizational competitiveness and operational effectiveness (Klein-Schmeink & Peisl, 2013). Through innovation, firms can develop new approaches to improve efficiency, reduce uncertainty, and enhance their responsiveness to environmental changes (Lee et al., 2011). Innovation contributes to multiple supply chain activities, including planning, procurement, forecasting, and monitoring, thereby supporting more effective risk management practices. Among the various forms of innovation, product innovation and process innovation are particularly relevant to manufacturing organizations. Product innovation focuses on the creation of new or improved products that address evolving market needs, whereas process innovation aims to enhance production efficiency, operational flexibility, and workflow effectiveness (Bergfors & Larsson, 2009). By integrating these innovation activities across supply chain functions, firms can better respond to demand fluctuations, market uncertainty, and unexpected disruptions (Huma et al., 2024). Investments in advanced machinery, digital technologies, and product development initiatives not only improve competitiveness but also strengthen organizational capabilities to anticipate and manage risks proactively (Wang & Hu, 2020; Haq et al., 2021). Without the capacity to recognize emerging threats and interpret environmental signals effectively, organizations may struggle to adapt and maintain supply chain continuity (Can Saglam et al., 2021).

Over the past two decades, SCRM has attracted considerable scholarly attention. Existing studies have examined various antecedents and outcomes of risk management practices, focusing on how firms identify, evaluate, and mitigate supply chain risks (Christopher & Peck, 2004; Durach et al., 2015; Hohenstein et al., 2015). Despite this growing body of research, empirical evidence regarding the role of innovation in strengthening supply chain risk management capabilities remains limited (Wong & Ngai, 2019). In particular, few studies have investigated how different forms of innovation, such as product innovation and process innovation, contribute to the development of resilience and robustness within supply chains (Golgeci & Ponomarov, 2013; Kwak et al., 2018). Although innovation and risk management are both recognized as critical determinants of organizational performance, their combined influence has not been fully explored.

Addressing this research gap, the present study examines the role of product innovation and process innovation in enhancing supply chain risk management capabilities, specifically resilience and robustness. By integrating these innovation dimensions within a unified conceptual framework, the study seeks to explain how innovation-oriented supply chain practices contribute to the development of stronger risk management capabilities. In doing so, this research aims to answer the following research question:

RQ1: How do product innovation and process innovation influence supply chain resilience and robustness in improving supply chain risk management performance?

This study contributes to the literature by advancing the understanding of the relationship between supply chain innovation and risk management. Specifically, it provides empirical evidence regarding the mechanisms through which product and process innovation function as strategic resources that enhance resilience and robustness, enabling organizations to respond effectively to disruptions and maintain supply chain performance under conditions of uncertainty.

2. Materials and Methods

This study is grounded in Dynamic Capabilities Theory (DCT), which explains how organizations adapt, integrate, and reconfigure resources to respond effectively to environmental changes and market turbulence (Teece et al., 1997; Teece, 2007). In increasingly uncertain business environments, supply chains are required to continuously sense disruptions, seize emerging opportunities, and transform operational capabilities to maintain competitiveness and organizational performance. According to DCT, sustainable competitive advantage depends not only on the possession of valuable resources but also on an organization's ability to deploy and reconfigure those resources in response to changing environmental conditions (Easterby-Smith & Prieto, 2008; Chowdhury & Quaddus, 2017). Within this perspective, innovation can be viewed as a dynamic capability that enables firms to identify supply chain disruptions through information technologies and market intelligence, capitalize on emerging opportunities through product and process adaptation, and reconfigure operational resources to restore performance during periods of uncertainty (Teece et al., 2016; Albort-Morant et al., 2018). Consequently, product innovation and process innovation are conceptualized as strategic capabilities that contribute to the development of supply chain resilience and robustness, thereby strengthening supply chain risk management capabilities.

Innovation is widely recognized as a critical driver of supply chain performance and risk mitigation. It involves the introduction of new knowledge, technologies, and ideas into organizational activities to improve products, processes, and business practices. According to the OECD Oslo Manual (2005), innovation can be classified into product, process, marketing, and organizational innovation, each contributing differently to value creation within supply chain networks (Gao et al., 2017; Karaman Kabadurmus, 2020). Among these forms, product innovation and process innovation are particularly important because of their direct influence on operational flexibility, responsiveness, and risk management effectiveness (Kwak et al., 2018; Afraz et al., 2021). Therefore, this study focuses specifically on product innovation and process innovation as key supply chain innovation practices that enhance supply chain risk management capabilities.

Product innovation refers to the development and introduction of new or substantially improved products and services that generate value for customers and supply chain partners. Product innovation enables organizations to acquire new competencies, establish strategic partnerships, and create differentiated offerings that improve their ability to operate under uncertain conditions (Gunday et al., 2011; Abdelaziz et al., 2023). Previous evidence demonstrates that organizations engaging in continuous product innovation are more capable of adapting to changing market demands and unexpected disruptions. For example, during the COVID-19 pandemic, the Italian company Isinnova rapidly transformed diving masks into emergency respirators to address shortages of ventilators, illustrating how product innovation can improve responsiveness and support supply chain continuity during crises (Ferrigno & Cucino, 2021). Similarly, firms in the personal care industry reconfigured production resources to manufacture hand sanitizers in response to sudden market shortages, demonstrating the strategic value of product innovation during disruptive events (Khan et al., 2019; Huma & Ahmed, 2022). Through continuous product development, diversification, and technological integration, organizations can improve their ability to respond to disruptions, thereby enhancing both resilience and robustness within supply chains (Kwak et al., 2018; Foli et al., 2024).

Process innovation refers to the implementation of new or significantly improved production, manufacturing, and delivery methods aimed at increasing operational efficiency and flexibility (Abdelaziz et al., 2023; Tidd, 2010). This form of innovation enables organizations to redesign workflows, adopt advanced technologies, and optimize operational processes to reduce vulnerability to disruptions. During the COVID-19 pandemic, numerous manufacturing firms rapidly adjusted production systems to produce personal protective equipment, ventilators, and sanitizers in response to urgent societal needs (Banks, 2020; Tognini, 2020). Likewise, Nike adopted radio-frequency identification technology to improve real-time visibility of inventory and demand fluctuations, thereby reducing uncertainty and improving responsiveness (Van Hoek, 2020). Such examples illustrate how process innovation enhances resilience by facilitating rapid operational adaptation while simultaneously strengthening robustness through the development of flexible and sustainable production systems. Continuous investment in process innovation improves organizational capabilities and strengthens collaboration among supply chain partners, enabling firms to anticipate, absorb, and recover from disruptions more effectively (Afraz et al., 2021; Huma & Siddiqui, 2025).

Supply chain risk management performance reflects the ability of an organization to identify, manage, and respond to risks and opportunities across the supply chain network. Two important dimensions of supply chain risk management capability are resilience and robustness (Wieland & Wallenburg, 2012; Ahmed & Huma, 2021). Robustness refers to the capability of a supply chain to maintain operational continuity and perform as expected despite disruptions or adverse events (Simchi-Levi et al., 2018). In contrast, resilience emphasizes the ability to recover quickly and adapt following disruptions while maintaining long-term operational effectiveness (Bevilacqua et al., 2018; Spiegler et al., 2012; Hosseini et al., 2019). Resilient supply chains focus on minimizing the negative consequences of disruptions through rapid adaptation and recovery, whereas robust supply chains emphasize resistance and continuity under challenging conditions. Together, these capabilities enable organizations to reduce the impact of risks, respond effectively to disturbances, and establish a sustainable framework for managing future disruptions (Ahmed & Huma, 2021). Prior studies consistently report that both resilience and robustness contribute positively to supply chain risk management performance (Can Saglam et al., 2021; Golgeci & Kuivalainen, 2020; Pettit et al., 2010).

Based on Dynamic Capabilities Theory and prior empirical findings, the following hypotheses are proposed:

H1a: Product innovation positively affects supply chain resilience.

H1b: Product innovation positively affects supply chain robustness.

H2a: Process innovation positively affects supply chain resilience.

H2b: Process innovation positively affects supply chain robustness.

H3a: Supply chain resilience positively affects supply chain risk management performance.

H3b: Supply chain robustness positively affects supply chain risk management performance.

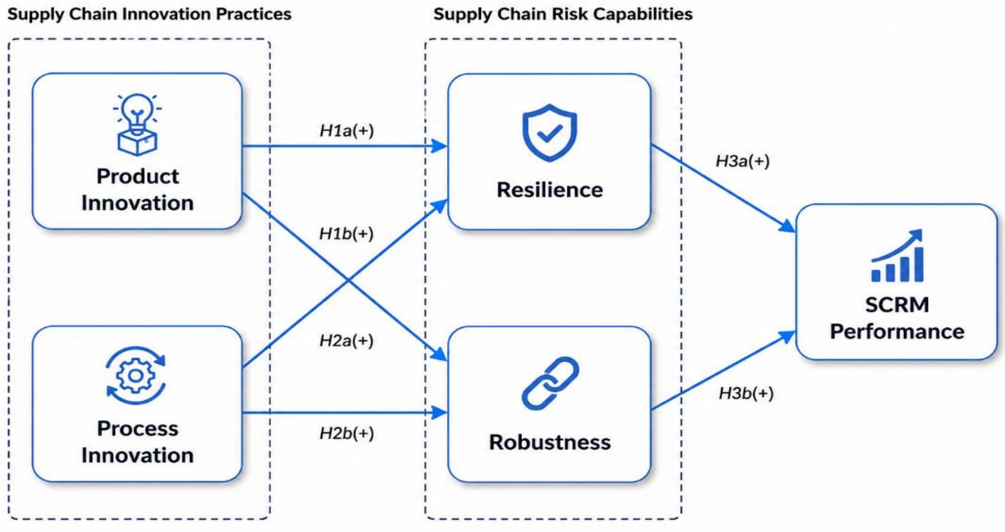

Figure 1. Proposed research framework. Source: Authors' estimation

This study adopts an explanatory research design to investigate the relationships among product innovation, process innovation, supply chain risk management (SCRM) capabilities, and SCRM performance within manufacturing firms. Explanatory research is particularly suitable for examining causal relationships between variables and understanding how different constructs interact to influence organizational outcomes (Bordens & Abbott, 2002). The study seeks to extend existing knowledge by developing and empirically validating an integrated framework that explains how innovation practices contribute to the development of supply chain resilience and robustness, ultimately improving SCRM performance.

Primary data were collected through a structured self-administered questionnaire. The instrument was initially developed based on established literature and subsequently refined through expert evaluation to ensure content relevance, clarity, and consistency with the study objectives. Revisions were incorporated following expert recommendations while preserving the conceptual integrity of the original constructs. In accordance with Hair et al. (2021), a post hoc statistical power analysis was conducted, confirming that the final sample size exceeded the recommended minimum requirement for a model containing six latent constructs. The analysis demonstrated that the sample size provided statistical power greater than 0.90 at a significance level of 0.05.

A purposive sampling technique was employed to identify suitable respondents from export-oriented manufacturing firms registered with the Securities and Exchange Commission of Pakistan (SECP). These firms collectively contribute more than 85% of Pakistan's export earnings (Abbas & Waheed, 2017). To ensure the relevance and quality of responses, participating organizations were required to be actively involved in international markets. Respondents were selected from middle- and senior-management positions across supply chain, production, quality assurance, marketing, and customer relationship functions, as these individuals possess substantial knowledge regarding supply chain operations and risk management practices. The sample represented a diverse range of manufacturing sectors, including pharmaceuticals, textiles and apparel, food and dairy products, automotive and parts manufacturing, electronics, fast-moving consumer goods, chemicals and petroleum, cement, surgical products, and packaging industries. This sectoral diversity enabled the study to capture variations in innovation adoption and risk management practices across industries.

Data collection was conducted through both offline and online channels. Offline data were gathered through direct interactions at professional conferences and industry events, while online responses were obtained through email distribution and professional networks. A total of 400 questionnaires were distributed, resulting in 292 returned surveys. After screening for completeness, consistency, and validity, 267 usable responses were retained for the final analysis.

Measurement items for all constructs were adapted from previously validated studies and selected based on their conceptual relevance and demonstrated psychometric properties. Detailed measurement items and their original sources are presented in Table 1. All variables were measured using a seven-point Likert scale ranging from 1 (“strongly disagree”) to 7 (“strongly agree”). To ensure content validity, the questionnaire was reviewed by subject-matter experts and pretested with a convenience sample of 30 supply chain professionals. Feedback from the pretest was used to improve wording, readability, and response clarity.

The reliability and validity of the measurement instrument were assessed through several statistical procedures. Construct validity was evaluated using confirmatory factor analysis (CFA) conducted in SmartPLS. Reliability was assessed through Cronbach’s Alpha and Composite Reliability (CR), with all constructs exceeding the recommended threshold of 0.70. Convergent validity was evaluated through factor loadings and average variance extracted (AVE), while discriminant validity was examined using both the Fornell–Larcker criterion and the Heterotrait–Monotrait ratio (HTMT). These procedures ensured that all constructs adequately captured their intended theoretical concepts and remained empirically distinct from one another.

Descriptive statistics were subsequently performed to summarize the characteristics of the respondents and participating organizations. The analysis included demographic information, industrial sector, functional area, annual export volume, and annual sales performance, as reported in Table 1.

Table 1. Demographic Profile

Demographics	Category	Frequency	Percent (%)
Manufacturing Industry	Pharmaceuticals	37	13.8
	Textile and Apparels	56	20.9
	Food and Dairy	39	14.6
	Auto and Parts Manufacturing	45	16.8
	Electronics	19	7.0
	FMCG	20	7.5
	Chemicals/Petroleum	10	3.74
	Cement	7	2.62
	Surgical Goods	6	2.3
	Packaging	13	4.9
	Other	15	5.6
Designation	Owner/Partner	35	13.2

Demographics	Category	Frequency	Percent (%)
	CEO/General Manager	16	6.0
	Functional Head	15	5.7
	Executive	41	15.4
	Sr. Manager	24	9.0
	Manager	55	20.5
	Engineer	39	14.7
	Other	42	15.8
Functional Area	Production	52	19.5
	Supply Chain	85	31.9
	Quality (QA/QC)	32	12.0
	Marketing/Customer Relationship	65	24.4
	Other	33	12.4
Annual Exports of Finished Goods	0%–20%	67	25.1
	20%–40%	75	28.1
	41%–60%	27	10.2
	61%–80%	58	21.8
	81%–100%	40	15.0
Annual Sales	Greater than 200 m	78	29.2
	51 m–100 m	48	18.0
	101 m–200 m	45	16.9
	10 m–50 m	60	22.5
	Less than 10 m	36	13.4
Total		**267**	**100**

To test the proposed conceptual model and hypotheses, Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed using SmartPLS 3.1 software. PLS-SEM was selected because of its suitability for analyzing complex models involving multiple latent constructs and its robustness when applied to small-to-moderate sample sizes (Hair et al., 2019). Following the recommended two-stage procedure, the measurement model was first evaluated to establish reliability and validity. Subsequently, the structural model was assessed to estimate path relationships and test the proposed hypotheses. Statistical significance was determined through a bootstrapping procedure using 5,000 resamples and a significance level of 5%.

Although PLS-SEM does not provide a universally accepted global goodness-of-fit index, it offers considerable advantages for predictive research, exploratory model development, and the analysis of latent variable relationships under conditions of non-normal data distribution. These characteristics make it particularly appropriate for investigating the proposed framework and examining the predictive relationships among innovation practices, SCRM capabilities, and performance outcomes.

Several procedural and statistical remedies were implemented to minimize the potential influence of common method variance (CMV). First, questionnaire items were designed using simple and unambiguous language to improve respondent comprehension. Second, respondents were assured of anonymity and confidentiality to encourage honest and unbiased responses (Podsakoff et al., 2003). Third, Harman's single-factor test was conducted to statistically assess the presence of CMV. The unrotated exploratory factor analysis revealed that the first factor accounted for only 26.1% of the total variance, well below the commonly accepted threshold, indicating that CMV was unlikely to threaten the validity of the findings. Finally, following Bagozzi et al. (1991), inter-construct correlations were examined and no correlation exceeded the critical value of 0.90. The highest observed correlation was 0.724, further confirming that common method bias was not a significant concern in this study.

3. Results and Discussion

The evaluation of the measurement model was conducted prior to testing the structural relationships among the study variables. Following the recommendations of Hair et al. (2013), the assessment included content validity, convergent validity, discriminant validity, predictive relevance, and hypothesis testing to ensure the robustness of the proposed model.

Content validity was first examined by assessing item loadings on their respective constructs. According to Chin (1998), factor loadings above 0.60 are considered acceptable and indicate that indicators adequately represent the intended latent constructs. As reported in Table 2, all retained measurement items exhibited significant loadings above the recommended threshold and loaded more strongly on their designated constructs than on any alternative construct. Several indicators with loadings below the acceptable threshold were removed from further analysis. These results confirm that the measurement model demonstrates satisfactory content validity (Hair et al., 2013).

Table 2. Factor Loadings and Significance of Measurement Items

Construct	Item	Loading	t-value	p-value	VIF
SCRMP	SCRMP1	0.763	8.145	0.000	1.733
	SCRMP2	0.826	15.194	0.000	2.830
	SCRMP3	0.842	9.966	0.000	3.458
	SCRMP4	0.848	15.583	0.000	2.320
	SCRMP5	0.788	8.239	0.000	2.450
PDI	PDI1	0.824	15.751	0.000	3.013
	PDI3	0.861	23.665	0.000	1.651
	PDI4	0.809	14.743	0.000	1.428
	PDI5	0.729	7.716	0.000	1.681
PCI	PCI2	0.825	13.261	0.000	2.132
	PCI3	0.905	38.110	0.000	1.623
	PCI5	0.797	12.779	0.000	1.633
RO	RO1	0.722	6.456	0.000	1.313
	RO3	0.868	18.479	0.000	2.105
	RO4	0.863	20.138	0.000	1.711
RE	RE1	0.725	11.877	0.000	2.045
	RE2	0.894	41.125	0.000	1.477
	RE3	0.760	7.720	0.000	2.734

Convergent validity was subsequently assessed using Composite Reliability (CR), Cronbach's Alpha, rho_A, and Average Variance Extracted (AVE). Convergent validity reflects the extent to which multiple indicators of the same construct share a high proportion of common variance (Hair et al., 2013). Following the criteria proposed by Fornell and Larcker (1981), CR values exceeding 0.70 and AVE values above 0.50 indicate adequate convergent validity. The results presented in Table 3 show that all constructs satisfied these requirements, confirming the reliability and convergent validity of the measurement model. Furthermore, all Variance Inflation Factor (VIF) values remained below the threshold of 3.3, indicating the absence of multicollinearity concerns among the constructs (Chin, 2010).

Table 3. Construct Reliability and Validity

Construct	Cronbach's Alpha	CR rhoA	Composite Reliability	AVE
SCRMP	0.872	0.875	0.907	0.662
PDI	0.821	0.827	0.882	0.651
PCI	0.797	0.816	0.881	0.712
RE	0.706	0.713	0.837	0.634
RO	0.768	0.834	0.860	0.673

Discriminant validity was evaluated using three complementary approaches, namely the Fornell–Larcker criterion, cross-loadings, and the Heterotrait–Monotrait ratio (HTMT). According to Fornell and Larcker (1981), the square root of AVE for each construct should exceed its correlations with other constructs. As reported in Table 4, all diagonal values representing the square root of AVE were greater than the corresponding inter-construct correlations, confirming satisfactory discriminant validity.

Table 4. Fornell–Larcker Criterion

Construct	SCRMP	PDI	PCI	RE	RO
SCRMP	**0.814**				
PDI	0.459	**0.807**			
PCI	0.169	0.324	**0.844**		
RE	0.537	0.651	0.066	**0.796**	
RO	0.114	0.518	0.424	0.156	**0.820**

Note: Diagonal values (bold) represent the square root of AVE.

The cross-loading analysis further supports this conclusion, as each measurement item loaded highest on its associated construct and exceeded cross-loadings on other constructs by the recommended margin (Gefen & Straub, 2005).

Table 5. Cross Loadings

Construct	SCRMP	PDI	PCI	RE	RO
SCRMP1	**0.763**	0.451	0.208	0.479	0.131
SCRMP2	**0.826**	0.238	0.055	0.389	0.066
SCRMP3	**0.842**	0.290	0.049	0.438	0.044
SCRMP4	**0.848**	0.520	0.220	0.452	0.303
SCRMP5	**0.788**	0.328	0.134	0.409	0.025
PDI1	0.293	**0.824**	0.193	0.440	0.388
PDI3	0.391	**0.861**	0.224	0.560	0.399
PDI4	0.337	**0.809**	0.411	0.416	0.643
PDI5	0.455	**0.729**	0.182	0.694	0.190
PCI2	0.155	0.242	**0.825**	0.069	0.358
PCI3	0.148	0.352	**0.905**	0.083	0.375
PCI5	0.124	0.210	**0.797**	0.007	0.340
RE1	0.427	0.543	0.096	**0.725**	0.198
RE2	0.463	0.521	-0.044	**0.894**	0.068
RE3	0.384	0.486	0.118	**0.760**	0.108
RO1	0.016	0.377	0.074	0.164	**0.722**
RO3	0.024	0.420	0.329	0.155	**0.868**
RO4	0.188	0.467	0.511	0.095	**0.863**

Note: Bold values indicate the highest loading of each indicator on its corresponding construct.

In addition, HTMT values reported in Table 6 remained below the recommended threshold of 1.00, providing further evidence that all constructs captured distinct conceptual domains (Henseler et al., 2015).

Table 6. HTMT Ratio Results

Construct	SCRMP	PDI	PCI	RE	RO
SCRMP	—				
PDI	0.530	—			
PCI	0.199	0.379	—		
RE	0.677	0.861	0.161	—	
RO	0.185	0.624	0.472	0.253	—

The predictive capability of the model was assessed using R^2 and Q^2 statistics. Hair et al. (2017) suggest that R^2 values exceeding 0.25 indicate acceptable explanatory power. The results reported in Table 7 reveal that the model explains 28.9% of the variance in supply chain risk management performance (SCRMP), indicating a moderate level of predictive power. Predictive relevance was further examined through the blindfolding procedure in SmartPLS. According to Stone (1974, 1977), positive Q^2 values indicate that the model possesses predictive relevance. The obtained Q^2 value of 0.158 confirms that the model has adequate predictive capability. Moreover, the Standardized Root Mean Square Residual (SRMR) value of 0.087 remained below the recommended threshold of 0.09, indicating an acceptable overall model fit.

Table 7. Predictive Power of Construct

Variable	R^2	Q^2
SCRMP	0.289	0.158

The structural model was subsequently evaluated through Partial Least Squares Structural Equation Modeling (PLS-SEM) using a bootstrapping procedure with 5,000 resamples, following the recommendations of Hair et al. (2016). The hypothesis testing results are summarized in Table 8 and illustrated in Figure 2.

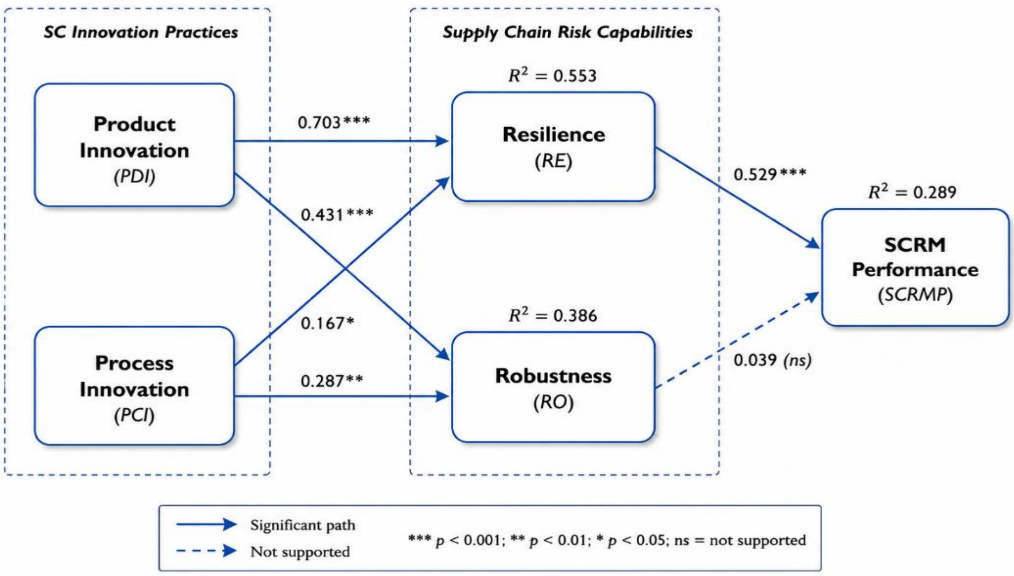

Figure 2. Structural Model and Hypothesis Testing Results

Table 8. Hypothesis Testing Results

Hypothesis	Path	Estimate (β)	S.D.	t-value	p-value	Decision
H1a	PDI → RE	0.703	0.078	9.035	0.000	Accepted
H1b	PDI → RO	0.431	0.125	3.403	0.001	Accepted
H2a	PCI → RE	0.167	0.081	1.991	0.047	Accepted
H2b	PCI → RO	0.287	0.102	2.795	0.005	Accepted
H3a	RE → SCRMP	0.529	0.115	4.606	0.000	Accepted
H3b	RO → SCRMP	0.039	0.113	0.270	0.787	Rejected

The findings demonstrate that product innovation exerts a positive and significant influence on both resilience and robustness capabilities. Specifically, product innovation significantly enhances resilience ($\beta = 0.703$, $p < 0.001$) and robustness ($\beta = 0.431$, $p = 0.001$), supporting Hypotheses H1a and H1b. These results suggest that firms investing in product innovation are better able to adapt to unexpected disruptions and maintain operational continuity during periods of uncertainty. Product innovation enables organizations to introduce alternative products, respond to changing customer needs, and create greater flexibility within supply chain networks. This finding is consistent with previous studies emphasizing the role of innovation in strengthening supply chain adaptability and risk management effectiveness (Kwak et al., 2018; Sabahi & Parast, 2020; Afraz et al., 2021).

The results further indicate that process innovation positively contributes to both resilience and robustness capabilities. Process innovation significantly affects resilience ($\beta = 0.167$, $p = 0.047$) and robustness ($\beta = 0.287$, $p = 0.005$), supporting Hypotheses H2a and H2b. These findings highlight the importance of improving operational processes, adopting advanced technologies, and enhancing workflow efficiency as mechanisms for reducing vulnerability to supply chain disruptions. Through process innovation, organizations can improve their responsiveness, maintain operational stability, and recover more effectively from unexpected events. This evidence further supports the argument that innovation serves as a critical enabler of supply chain risk management capabilities (Kwak et al., 2018; Sabahi & Parast, 2020; Afraz et al., 2021).

With regard to the relationship between supply chain risk management capabilities and performance, resilience was found to have a positive and significant impact on SCRM performance ($\beta = 0.529$, $p < 0.001$), thereby supporting Hypothesis H3a. This result indicates that organizations possessing stronger resilience capabilities are better able to absorb disruptions, recover from adverse events, and sustain operational performance under uncertain conditions. The finding aligns with previous studies suggesting that adaptability, organizational learning, and recovery capabilities are among the most important determinants of successful supply chain risk management outcomes (Can Saglam et al., 2021). Furthermore, resilience enables organizations to tolerate systemic risks while simultaneously adjusting to evolving environmental conditions, thereby contributing to superior risk management performance (Starr et al., 2003).

In contrast, the relationship between robustness and SCRM performance was not statistically significant ($\beta = 0.039$, $p = 0.787$), leading to the rejection of Hypothesis H3b. Although robustness has often been viewed as a critical capability for maintaining operational continuity during disruptions (Bevilacqua et al., 2018; Hosseini et al., 2019), the findings suggest that robustness alone may not be sufficient to enhance overall SCRM performance in highly dynamic export-oriented environments. One possible explanation is that robustness must be aligned with the specific risk profile and environmental conditions of the supply chain. Excessive emphasis on stability and resistance may reduce organizational flexibility and limit the ability to adapt to rapidly changing circumstances. Consequently, the expected performance benefits of robustness may not materialize unless it is complemented by adaptive capabilities such as resilience.

Overall, the results demonstrate that innovation-oriented supply chain practices significantly contribute to the development of resilience and robustness capabilities. However, resilience emerges as the more influential capability in driving supply chain risk management performance. These findings reinforce the importance of developing adaptive and innovative supply chain systems capable of responding effectively to increasing environmental uncertainty and disruption.

4. Conclusions

In an increasingly uncertain and interconnected supply chain environment, innovation has become a crucial capability for organizations seeking to improve supply chain risk management (SCRM) performance. This study examined the effects of product innovation and process innovation on two key SCRM capabilities, namely resilience and robustness, and further assessed how these capabilities contribute to overall SCRM performance. The findings reveal that both product innovation and process innovation significantly enhance resilience and robustness within supply chains. However, resilience emerged as the more influential capability in improving SCRM performance, highlighting the importance of adaptability, organizational learning, and resource reconfiguration when responding to unexpected disruptions. Although robustness contributes to maintaining operational continuity, its influence appears less pronounced in highly dynamic and uncertain business environments. These findings suggest that innovation functions as a strategic mechanism that enables organizations to strengthen risk management capabilities and sustain performance under challenging conditions. Consistent with Dynamic Capabilities Theory (DCT), product and process innovation provide firms with the ability to identify emerging risks, capitalize on new opportunities, and reconfigure resources in response to environmental changes, thereby fostering the development of more resilient supply chains.

This study contributes to the literature by providing both theoretical and empirical evidence regarding the relationship between innovation and SCRM capabilities. Unlike prior studies that predominantly focused on either product innovation (Wu et al., 2016; Aydin, 2020; Dos Santos et al., 2023) or process innovation (Maruyama & Zennyo, 2017; Ashok et al., 2018; Radnejad et al., 2020; Wedajo et al., 2022), the present study integrates both dimensions within a single framework and demonstrates their combined contribution to resilience and robustness. Through the lens of Dynamic Capabilities Theory, product and process innovation can be viewed as micro-foundations that support sensing, seizing, and reconfiguring activities within organizations (Teece et al., 2016; Albort-Morant et al., 2018). The findings further clarify that resilience is a more critical determinant of SCRM performance than robustness, particularly in volatile and export-oriented environments where agility, learning, and adaptive capabilities are essential for long-term success (Ali et al., 2023; Ivanov, 2024). These results strengthen the theoretical understanding of how innovation-driven capabilities contribute to risk management effectiveness and sustainable competitive advantage.

From a managerial perspective, the findings suggest that organizations should prioritize investments in innovation initiatives that enhance flexibility, information visibility, and learning capabilities throughout the supply chain. The adoption of digital monitoring technologies, real-time data analytics, adaptive production systems, and knowledge-sharing platforms can improve the ability of firms to detect disruptions, respond rapidly, and recover efficiently from unexpected events (Golgeci & Ponomarov, 2013). In addition, continuous process improvement through workflow redesign, automation, and operational optimization can reduce inefficiencies and strengthen organizational robustness. Managers are also encouraged to promote collaborative innovation with suppliers, customers, and logistics partners to enhance collective preparedness and responsiveness to supply chain disruptions. Overall, the results indicate that innovation investments focused on adaptability, information sharing, and operational flexibility generate greater long-term benefits than approaches relying primarily on redundancy and static stability. Consequently, fostering an innovation-oriented risk management culture can serve as an effective strategy for maintaining operational continuity, strengthening competitiveness, and supporting sustainable organizational performance in increasingly uncertain markets.

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