FROM CANE TO CHAIN: THE ROLE OF DIGITALIZATION AND RISK MANAGEMENT IN SUGAR SUPPLY EFFICIENCY

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Abstract

This study investigates the impact of supply chain digitalization on supply chain performance in Pakistan's sugar industry, emphasizing the moderating role of supply chain risk management. While digital transformation is increasingly recognized as a driver of operational excellence, its effectiveness in developing economies especially in agro-industrial sectors remains underexplored. Using a quantitative approach, data were collected from 400 supply chain professionals across seven sugar mills in Khyber Pakhtunkhwa through structured questionnaires. Regression analysis and Hayes' PROCESS macro were employed to test the proposed relationships. The findings reveal that supply chain digitalization significantly enhances performance by improving efficiency and reducing operational costs. Moreover, supply chain risk management strengthens this relationship, indicating that firms with effective risk management systems derive greater benefits from digital initiatives. The study contributes to the literature by integrating digitalization with contingency theory, highlighting that the performance gains from digital technologies are contingent upon organizational risk preparedness. Practically, the findings suggest that agro-industrial firms in developing economies should align digital investments with robust risk management frameworks to

fully realize performance improvements. Future research may consider exploring cross-sectoral generalizability and long-term impact.

Keywords: Supply Chain Performance, Supply Chain Digitalization, Supply Chain Risk Management, Sugar Industry

Background of the Study

In the last decade, advanced developments in the digital economy and decentralized business structures through BCT have reshaped supply chain dynamics (Dwivedi et al., 2023; Zheng & Lu, 2022). Technological advancements, particularly those related to BCT, have transformed platform economies, rendering traditional supply chain management (SCM) practices insufficient and requiring enhanced digital capabilities.

The adoption of Industry 4.0 technologies such as IoT, AI, and blockchain has converted global supply chains from siloed, linear structures to interconnected ecosystems (Ivanov et al., 2022). These tools enable real-time data exchange, predictive analytics, and automation, which improve agility and competitiveness (Wieland & Durach, 2021). To address increasing complexity and uncertainty, technologies like BCT are being deployed to optimize SCM by improving shipment visibility, enhancing security, supporting product development flexibility, and reducing inventory-related risks (Nandi et al., 2020; Hastig & Sodhi, 2020; Wang et al., 2021).

Empirical studies confirm that digitalization significantly reduces latency and enhances forecasting accuracy, thereby addressing longstanding inefficiencies in traditional systems (Barykin et al., 2023). This has shifted competitive focus from individual firms to integrated supply chain systems composed of multiple interconnected entities (Büyüközkan & Göçer, 2018). The COVID-19 pandemic further exposed critical weaknesses in traditional supply chains, accelerating digital transformation across sectors such as logistics and healthcare (McKinsey, 2023; Ivanov & Dolgui, 2023).

Despite these advances, challenges persist particularly in developing regions— due to cybersecurity risks, talent shortages, and organizational inertia (IBM Security, 2023; Sodhi et al., 2023). Such complexities necessitate robust supply chain risk management (SCRM) systems that can reinforce and amplify the performance benefits of digital initiatives.

Recent studies have acknowledged the need to explore conditions under which supply chain digitalization leads to improved outcomes. For example, Harju et al., (2023) highlight how digitalization within procurement can reduce uncertainty and mitigate operational risks, suggesting the importance of aligning digital transformation with risk management strategies. Zhao et al., (2024) and Ivanov (2020) emphasize the significance of understanding risk variables, such as technological disruptions and epidemics, that may impose long-lasting effects on supply chains. These works collectively call for further research on how supply chain risk management can enhance the effectiveness of digital technologies in building flexible, sustainable, and high-performing supply chains.

While prior studies have advanced knowledge of digital transformation in global contexts, there remains a significant gap in understanding how SCRM functions as a moderator in the relationship between digitalization and performance, especially in resource-constrained regions. Limited empirical work has explored this dynamic within the agro-industrial sectors of developing economies, such as Pakistan's sugar industry, which faces institutional fragility, infrastructural limitations, and heightened operational volatility. This study addresses this gap by investigating how SCRM strengthens the relationship between supply chain digitalization and supply chain performance in the sugar industry of Khyber Pakhtunkhwa.

Problem Statement

The COVID-19 pandemic highlighted major vulnerabilities in global supply chains, prompting accelerated adoption of supply chain digitalization (SCD) to ensure operational continuity and resilience (Holmstrom et al., 2019;

Ardolino et al., 2022). Technologies such as AI, blockchain, and big data have emerged as key enablers, improving visibility, efficiency, and adaptability in dynamic environments (Dubey et al., 2020b; Song et al., 2020). However, while digitalization has been linked to enhanced performance and responsiveness (Eller et al., 2020; Ivanov et al., 2022), little is known about the boundary conditions under which these benefits are realized.

In developing economies like Pakistan, where infrastructural and institutional limitations prevail, the role of supply chain risk management (SCRM) may be critical. Firms with strong risk management frameworks may extract greater performance value from digital tools. Yet, empirical research examining how SCRM moderates the SCD performance relationship, especially in resource-constrained agro-industrial sectors, remains limited. Addressing this gap, the present study investigates the moderating role of SCRM in the relationship between SCD and supply chain performance in the context of Pakistan's sugar industry.

Research Questions

RQ1: Does supply chain digitalization has significant impact on supply chain performance?

RQ2: Does supply chain risk management significantly moderated upon supply chain digitalization and supply chain performance?

Research Objectives

RO1: To investigate that supply chain digitalization has significant impact on supply chain performance.

RO3: To examine that supply chain risk management significantly moderated upon supply chain digitalization and supply chain performance.

Significance of the Study

This study contributes to academia, industry, and policymaking by examining the impact of supply chain digitalization (SCD) on performance in the sugar industry of Khyber Pakhtunkhwa, Pakistan an area underrepresented in existing literature (Ivanov et al., 2023). The sugar sector contributes around

0.6% to Pakistan's GDP and supports over 1.5 million people, making its supply chain efficiency vital for economic and rural development (Pakistan Economic Survey, 2023).

Unlike prior studies that focused on developed economies, this research provides empirical insights tailored to developing regions with infrastructural and institutional challenges. In particular, it highlights the moderating role of supply chain risk management (SCRM) in enhancing the performance outcomes of digital initiatives critical for navigating volatility and uncertainty in Pakistan's industrial context.

From a policy perspective, the findings offer actionable recommendations to shape digitization incentives and regulatory frameworks suitable for low-connectivity environments. With Pakistan ranked 110th in the UN E-Government Development Index (ITU, 2023), this study identifies strategic levers to overcome adoption barriers such as energy shortages and cybersecurity risks (State Bank of Pakistan, 2023).

For practitioners, the study outlines cost-effective digital interventions for small and medium enterprises, helping prioritize tools like IoT for yield tracking and blockchain for price transparency (FAO, 2023). It also supports resilience-building through workforce training and adaptive supply chain structures key in facing climate shocks and political instability (IMF, 2023).

Theoretically, it expands supply chain literature by framing a "lean digitalization" model relevant to resource-constrained environments (Wieland & Durach, 2023), offering transferable lessons to other emerging markets striving for efficiency without large capital investment (McKinsey, 2023).

Literature Review

Supply Chain Management Practices

Supply chain management (SCM) practices are essential for ensuring operational efficiency, cost control, and customer satisfaction. Core practices include supplier relationship management (Li et al., 2006), inventory control through JIT and VMI (Waller et al., 1999), demand forecasting using CPFR

(Sanders & Graman, 2009), and lean-agile integration (Womack & Jones, 2003; Christopher & Towill, 2001). Technology such as ERP, blockchain, and IoT has transformed SCM through enhanced transparency and real-time responsiveness (Saberi et al., 2019; Bi et al., 2014). Risk management strategies like diversification and predictive analytics (Tang, 2006; Jüttner et al., 2003), alongside sustainability efforts like green procurement and reverse logistics (Seuring & Müller, 2008; Genovese et al., 2017), ensure long-term viability. Performance measurement via KPIs and the balanced scorecard (Beamon, 1999) supports continuous improvement. Collaboration, integration (Simatupang & Sridharan, 2002; Flynn et al., 2010), and outsourcing to 3PL providers (Razzaque & Sheng, 1998) enhance responsiveness but require risk assessment (Manuj & Mentzer, 2008). As highlighted by Ivanov et al. (2019) and Zhao et al. (2023), integrating digitalization and sustainability is crucial for building resilient, adaptive, and competitive global supply chains.

Supply Chain Digitalization

Supply chain digitalization is now essential for building resilient, efficient, and responsive operations (Zhao et al., 2023). Technologies like blockchain, IoT, and AI are transforming linear supply chains into interconnected digital ecosystems (Ivanov et al., 2022). Digitally mature supply chains show 50% faster disruption response and 20% lower costs (McKinsey & Company, 2023), with blockchain enhancing transparency and reducing counterfeit risks by up to 35% (Zhang et al., 2024). Despite integration challenges with legacy systems (Gartner, 2023), firms like Walmart have achieved significant traceability gains (Walmart Inc., 2023). IoT adoption has cut spoilage rates by 30% in cold chains (FDA, 2023) and improved fleet efficiency and maintenance outcomes (Deloitte, 2024), though cybersecurity threats remain prevalent (IBM Security, 2023). AI has improved demand forecasting accuracy by over 40% and reduced inventory costs (Accenture, 2023; Amazon Annual Report, 2023), but concerns about algorithmic bias persist (MIT Sloan Management Review, 2023). Cloud platforms, used by 89% of firms, support

real-time processing via edge computing, improving agility and planning (Cisco, 2023; Harvard Business Review, 2024). Still, data sovereignty concerns drive hybrid cloud adoption (IDC, 2023). Digital transformation enhances resilience (MIT, 2023) and sustainability (WEF, 2023), though 62% of initiatives still fall short due to internal resistance (KPMG, 2024). Emerging tools like digital twins, autonomous delivery, and 5G-powered automation are reshaping supply chains (Capgemini, 2023; McKinsey, 2023; Ericsson, 2023). Strategic, problem-driven implementation, rather than tech-centric efforts, is vital for success (HBR, 2024), as firms shift toward "cognitive supply networks" that blend human and AI intelligence (Sodhi & Tang, 2023).

Supply Chain Performance

Supply chain performance is increasingly recognized as a multi-dimensional construct encompassing financial, operational, and sustainability metrics (Taticchi et al., 2015). Strong supply chain performance correlates with enhanced competitiveness and customer satisfaction (Huo et al., 2023). Frameworks such as the balanced scorecard have evolved to integrate responsiveness and innovation (Bhagwat & Sharma, 2007).

Supply chain integration, particularly in volatile environments, significantly boosts performance by reducing lead times and improving quality (Flynn et al., 2010; Wiengarten et al., 2023). Digital tools such as AI and blockchain contribute to performance by improving visibility and decision-making efficiency (Wang et al., 2023; Barykin et al., 2023).

Sustainability and human capital are also key performance drivers. Sustainable practices enhance long-term profitability (Eccles et al., 2023), while training investments improve adaptability and innovation (Ellinger et al., 2023). Organizational culture, including cross-functional collaboration and psychological safety, further elevates supply chain performance (Schein et al., 2023).

Relationship between Supply Chain Digitalization and Supply Chain Performance

Supply chain digitalization has emerged as a vital driver of performance enhancement across industries. Research consistently highlights how digital tools such as AI, IoT, and blockchain significantly improve efficiency, responsiveness, and resilience. For instance, companies using AI-driven demand forecasting report inventory reductions of 20–30% and improved stock availability by 15–25% (Accenture, 2023), while IoT-based tracking systems lower logistics costs by up to 15% (Deloitte, 2024). Blockchain's smart contracts reduce procurement transaction costs by 40% (IBM, 2023), collectively contributing to a 17% drop in operational costs for digitally mature supply chains (McKinsey & Company, 2024).

Digital platforms enhance visibility and coordination, reducing lead times by 25–35% (Gartner, 2023). Technologies like digital twins and AI analytics enable predictive decision-making, allowing firms to manage demand fluctuations with up to 90% accuracy (MIT Center for Transportation & Logistics, 2023). During the COVID-19 crisis, digitally advanced firms adjusted operations in real time and reduced revenue losses by 15–20% (Harvard Business Review, 2023).

Digitalization also supports supply chain resilience and sustainability. Blockchain ensures traceability, reducing counterfeit risks by 35% in pharmaceuticals (FDA, 2024), while IoT tools cut stockouts by 25% (DHL, 2023). Sustainability gains include a 10–20% drop in emissions through AI-driven logistics and enhanced ESG compliance via blockchain (World Economic Forum, 2023; PwC, 2024). These outcomes translate into strong financial performance—Amazon and Nike have both documented billions in savings and margin improvements due to supply chain digital transformation (Harvard Business Review, 2024).

Despite its benefits, digital transformation faces challenges. Barriers include limited budgets, cybersecurity threats, and talent shortages (Gartner, 2024;

IBM, 2023; Deloitte, 2024). These factors suggest that digitalization's impact on performance is influenced by firm-specific resources and external conditions (Sodhi & Tang, 2023).

In sum, supply chain digitalization offers substantial gains in efficiency, resilience, and sustainability, but its full potential depends on effective risk management and organizational readiness.

Moderating Role of Supply Chain Risk Management

SCRM also acts as a moderator in the relationship between supply chain digitalization and performance. While digital tools improve visibility, integration, and responsiveness, their effectiveness depends on the firm's ability to manage emerging risks (Wieland & Durach, 2023; Ivanov & Dolgui, 2023).

From a theoretical lens, dynamic capabilities theory suggests that SCRM enhances an organization's ability to translate digital capabilities into tangible results (Teece, 2023). For instance, technologies like IoT or blockchain improve data accuracy, but without risk protocols in place, disruptions may still cascade (Kouhizadeh et al., 2023).

Firms with mature risk management derive greater benefits from digitalization such as reduced lead times and improved demand forecasting compared to those lacking structured SCRM systems (Craighead et al., 2023). Additionally, SCRM helps mitigate risks introduced by digital adoption itself, such as cybersecurity and data privacy issues (Sodhi et al., 2023).

The COVID-19 pandemic highlighted this synergy: firms that combined digital tools with proactive risk management maintained higher supply chain continuity and performance levels (Dubey et al., 2023). Empirical studies support this moderating role, showing that performance gains from digitalization are significantly stronger in high-SCRM environments (Brandon-Jones et al., 2023).

In summary, SCRM is not only a performance driver but also a strategic enabler that strengthens the digitalization–performance link. For supply

chains in high-risk or resource-constrained sectors, this interplay becomes particularly critical for sustaining long-term competitiveness.

Conceptual Framework of the Study
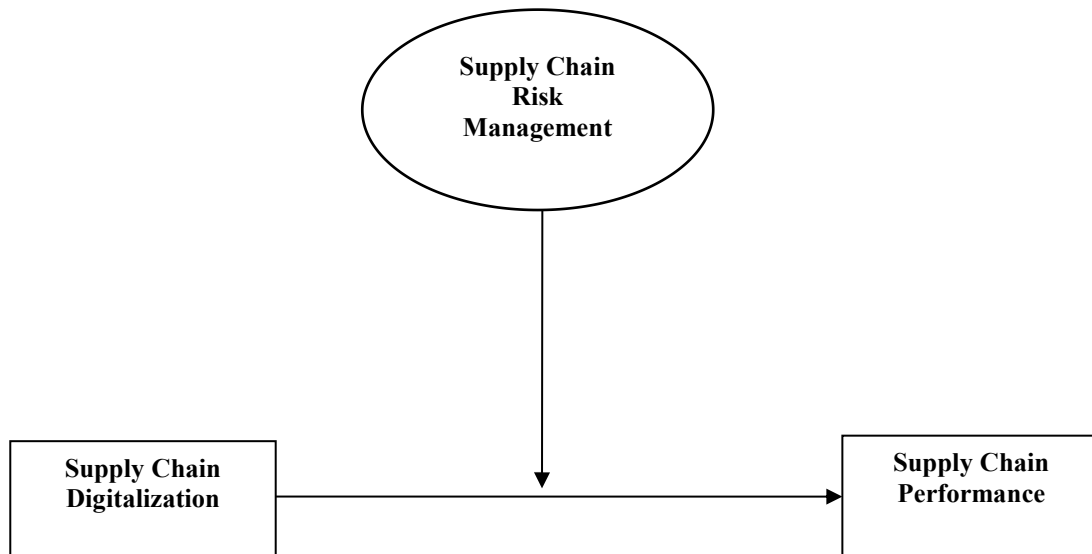
Research Hypotheses

H1: Supply chain digitalization has significant impact on supply chain performance.

H2: Supply chain risk management significantly moderated upon supply chain digitalization and supply chain performance.

Methodology

This study followed a post-positivist research philosophy, emphasizing objective measurement and empirical testing of hypothesized relationships. A quantitative, cross-sectional survey design was adopted to investigate the moderating role of Supply Chain Risk Management (SCRM) in the relationship between Supply Chain Digitalization (SCD) and Supply Chain Performance (SCP). The target population comprised employees working in sugar mills across Khyber Pakhtunkhwa (KP), Pakistan, due to their operational relevance and direct involvement in supply chain processes. A convenience sampling technique was used to collect data from respondents, given the accessibility constraints and the dispersed nature of the industry.

Standardized and previously validated scales were used to ensure the reliability and validity of constructs. Supply Chain Digitalization was measured using a three-item index adapted from Ageron et al. (2020), Weking et al. (2020), Frank et al. (2019), and Hallikas et al. (2021). Supply Chain Performance was assessed using a four-item scale adopted from Gu et al. (2021), Katiyar et al. (2018), and Beamon (1999). Supply Chain Risk Management was evaluated with four constructs developed by Hallikas and Lintukangas (2016), capturing various dimensions of risk handling and mitigation. The collected data were entered and analyzed using SPSS software, which facilitated descriptive analysis, correlation testing, and moderation analysis to examine the hypothesized relationships.

Data Analysis

Correlation Analysis

		SCD	SCRM	SCP
SCD	Pearson Correlation	1		
	Sig. (2-tailed)			
	N	400		
SCRM	Pearson Correlation	.684**	1	
	Sig. (2-tailed)	.000		
	N	400	400	
SCP	Pearson Correlation	.729**	.838**	1
	Sig. (2-tailed)	.000	.000	
	N	400	400	400

The correlation table presents Pearson correlation coefficients among the variables: Supply Chain Digitalization (SCD), Supply Chain Risk Management (SCRM), and Supply Chain Performance (SCP), based on a sample of 400 respondents.

The results indicate a strong positive and statistically significant correlation between SCD and SCRM (r = .684, p < .01), suggesting that increased

digitalization in the supply chain is associated with higher engagement in risk management practices. Additionally, SCD shows a strong and significant correlation with SCP ($r = .729$, $p < .01$), indicating that digitalization positively relates to performance outcomes in the supply chain. Furthermore, SCRM is very strongly and significantly correlated with SCP ($r = .838$, $p < .01$), implying that effective risk management contributes positively to supply chain performance. All correlations are significant at the 0.01 level (2-tailed), denoting a high level of confidence in these relationships.

Simple Linear Regression Analysis

H1: Supply chain digitalization has significant impact on supply chain performance.

Table a) Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.729[a]	.532	.531	.58146	.532	452.723	1	398	.000

a. Predictors: (Constant), SCD

b. Dependent Variable: SCP

A simple linear regression analysis was performed to assess the extent to which Supply Chain Digitalization (SCD) predicts Supply Chain Performance (SCP). The results showed that the model was statistically significant, $F(1, 398) = 452.72$, $p < .001$. SCD explained 53.2% of the variance in SCP ($R^2 = .532$), with an adjusted R^2 of .531. The standard error of the estimate was 0.58, reflecting the average deviation of the actual SCP scores from the predicted values.

Table b) Coefficients

Model		B	Std. Error	Beta	T	Sig.
		Unstandardized Coefficients		Standardized Coefficients		
1	(Constant)	.791	.074		10.720	.000
	SCD	.670	.031	.729	21.277	.000

a. Dependent Variable: SCP

A simple linear regression analysis was conducted to examine the predictive role of Supply Chain Digitalization (SCD) on Supply Chain Performance (SCP). The model was statistically significant, with the intercept coefficient B = 0.791 (SE = 0.074), t(398) = 10.72, p < .001, and the slope coefficient for SCD also significant at B = 0.670 (SE = 0.031), t(398) = 21.28, p < .001. The standardized beta coefficient (β = .729) indicates a large effect size, suggesting that higher levels of digitalization are strongly associated with improved supply chain performance. These results demonstrate that for every one-unit increase in SCD, SCP increases by approximately 0.670 units.

Moderation of Supply Chain Risk Management upon Supply Chain Digitalization and Supply Chain Performance

Model Summary

R	R-sq	MSE	F	df1	df2	P
.8691	.7553	.1777	407.4172	3.0000	396.0000	.0000

Model

|	coeff	Se	t	p	LLCI	ULCI
constant	.8054	.1899	4.2410	.0000	.4320	1.1787
SCD	.0292	.0777	.3759	.7072	-.1236	.1820
SCRM	.3778	.0902	4.1881	.0000	.2005	.5552
Int_1	.1006	.0298	3.3756	.0008	.0420	.1591

Outcome Variable: SCP

Table b)

Test(s) of highest order unconditional interaction(s):

	R2-chng	F	df1	df2	P
X*W	.0070	11.3949	1.0000	396.0000	.0008

Here is the rephrased version of your moderation analysis, refined for clarity and fit for inclusion in a research article:

A moderation analysis was conducted to assess whether Supply Chain Risk Management (SCRM) influences the strength of the relationship between Supply Chain Digitalization (SCD) and Supply Chain Performance (SCP). The model was statistically significant, $F(3, 396) = 407.42$, $p < .001$, accounting for 75.5% of the variance in SCP ($R^2 = .755$). The interaction term (SCD × SCRM) was also significant, $B = 0.101$, $SE = 0.030$, $t = 3.38$, $p = .001$, 95% CI \[0.042, 0.159], indicating that SCRM significantly moderates the impact of SCD on SCP.

The positive coefficient of the interaction term suggests that higher levels of risk management capability enhance the positive effect of digitalization on supply chain performance. Although the direct effect of SCD became non-significant when the interaction was included ($B = 0.029$, $SE = 0.078$, $t = 0.38$, $p = .707$), SCRM remained a significant predictor of SCP ($B = 0.378$, $SE = 0.090$, $t = 4.19$, $p < .001$). The R^2 change of .007 ($p = .001$) confirms that the interaction adds unique explanatory power to the model, beyond the individual effects of SCD and SCRM.
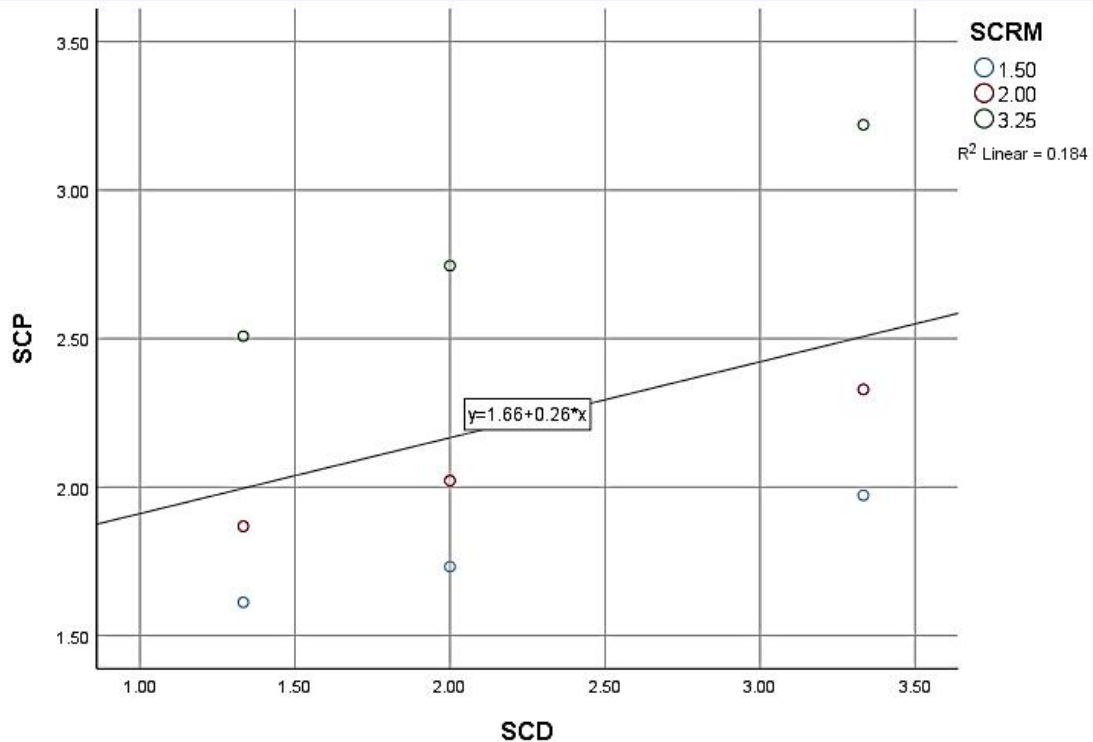
Moderation Graph

The scatterplot depicts the moderating effect of Supply Chain Risk Management (SCRM) on the relationship between Supply Chain Digitalization (SCD) and Supply Chain Performance (SCP). Three levels of SCRM are visualized through different colored markers: low (1.50) in blue, medium (2.00) in red, and high (3.25) in green.

The fitted regression line, defined by the equation **y = 1.66 + 0.26x**, represents the general trend showing that as digitalization increases, performance also tends to increase. The positive slope (0.26) indicates a modest upward trend. The R^2 = 0.184 suggests that 18.4% of the variance in SCP is explained by SCD at this level.

Importantly, the green (high SCRM) points tend to cluster above the regression line, indicating stronger performance outcomes for the same levels of digitalization, while the blue (low SCRM) points generally fall below the line. This pattern supports the moderation effect: firms with higher risk

management capabilities benefit more from digitalization in terms of performance, whereas firms with lower SCRM show weaker gains.

Discussion

The findings of this study offer strong support for both hypothesized relationships, contributing valuable insights into the role of Supply Chain Digitalization (SCD) and Supply Chain Risk Management (SCRM) in enhancing Supply Chain Performance (SCP) within Pakistan's sugar industry.

H1: Supply chain digitalization has a significant impact on supply chain performance.

The results confirm that digitalization significantly improves supply chain performance, aligning with prior studies by Büyüközkan and Göçer (2018) and Ivanov et al. (2022), who emphasized that technologies such as IoT, blockchain, and AI enhance efficiency, lower costs, and increase agility. In Pakistan's sugar sector, digital solutions address inefficiencies in cane procurement, inventory management, and logistics. Saberi et al. (2023) noted blockchain-enabled traceability promotes transparency critical in a sector where procurement irregularities often lead to financial losses (Pakistan Economic Survey, 2022). However, high implementation costs and limited technical expertise remain barriers, highlighting the need for policy support and training to facilitate effective adoption.

H2: Supply chain risk management moderates the digitalization-performance relationship.

The moderation analysis reveals that SCRM significantly strengthens the positive effect of SCD on SCP, supporting Wieland and Durach's (2023) "force multiplier" perspective, where risk management enhances digital investment outcomes. Practically, platforms with supplier risk scoring (IBM, 2023) and AI-based forecasting tools (FAO, 2023) are more effective when paired with sound risk mitigation strategies. For Pakistani sugar mills, digitalization must be complemented by cybersecurity measures and contingency solutions such

as backup energy systems to address vulnerabilities like power outages and supply disruptions (State Bank of Pakistan, 2023).

Overall, the study challenges the assumption that technology alone drives performance gains. Instead, it underscores the synergistic value of integrating digitalization with strong risk management, especially in developing economies where systemic vulnerabilities are more pronounced

Practical Implications

This study offers valuable guidance for managers and policymakers in Pakistan's sugar industry aiming to improve supply chain performance through digital transformation. The significant impact of supply chain digitalization (SCD) on performance highlights the urgent need for firms to invest in technologies such as blockchain, IoT, and AI-based analytics. These tools can streamline critical processes such as cane procurement, inventory tracking, and distribution, directly addressing long-standing inefficiencies in the sector. Managers should prioritize digital infrastructure development and allocate resources to integrate these tools into daily operations.

Furthermore, the moderating role of supply chain risk management (SCRM) reveals that digital tools alone are insufficient without a robust risk management framework. Firms must simultaneously develop strategies for identifying, assessing, and mitigating risks such as supply disruptions, cyber threats, and energy shortages. Investing in risk-scoring systems, data backup protocols, and alternative energy solutions will enhance the effectiveness of digital platforms. Risk management should not be viewed as a separate function but as a complementary pillar that strengthens digitalization efforts.

At the policy level, government agencies and industry bodies should offer financial incentives, training programs, and technical support to accelerate digital adoption, especially for small- and medium-sized mills that may lack internal capabilities. Public-private partnerships could play a vital role in reducing the digital divide and ensuring widespread capability development across the sector. By adopting a dual approach that promotes

both digital innovation and resilient risk management, stakeholders can unlock significant performance gains and ensure long-term competitiveness in the sugar supply chain.

Conclusion

In conclusion, this study confirms that supply chain digitalization significantly enhances supply chain performance in Pakistan's sugar industry, and this relationship is further strengthened by effective supply chain risk management practices. The findings underscore that digital transformation alone is not sufficient to drive sustainable performance improvements; it must be complemented by robust risk mitigation strategies that address the sector's specific vulnerabilities, such as power disruptions, procurement irregularities, and cyber threats. By adopting integrated approaches that combine technological innovation with proactive risk management, firms can unlock greater efficiency, transparency, and responsiveness. These insights provide a strategic roadmap for both industry leaders and policymakers aiming to modernize agro-industrial supply chains in developing economies.

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