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DIGITALIZATION AND SUSTAINABLE SUPPLY CHAIN QUALITY MANAGEMENT: POST-COVID PERSPECTIVES

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Original research

A B S T R A C T

The COVID-19 pandemic revealed structural vulnerabilities in global supply chains, highlighting the urgent need for sustainable, resilient, and digitally enabled supply chain management models. This study investigates the role of digitalization in enhancing sustainable supply chain quality management from a post-COVID perspective, with particular focus on digital tools, the integration of environmental, social, and governance (ESG) indicators, and firm resilience under uncertainty. The research analyzes how advanced digital technologies-such as big data analytics, artificial intelligence, blockchain, and the Internet of Things-improve transparency, traceability, risk management, and overall supply chain performance. Using a quantitative research design and Partial Least Squares Structural Equation Modeling (PLS-SEM), the findings demonstrate that aligning digitalization with sustainability significantly strengthens supply chain resilience and decision-making quality. The study provides theoretical and practical insights for managers and policymakers on aligning digital investments with ESG objectives to enhance operational performance and process quality. These findings offer actionable insights for managers and policymakers seeking to align digital investments with ESG objectives.

1. INTRODUCTION

Contemporary supply chains operate in an environment characterized by increasing complexity, global interdependence, and frequent disruptions caused by economic, geopolitical, technological, and environmental factors. Recent global crises, including the COVID-19 pandemic, have acted as a systemic stress test, exposing structural weaknesses in traditional supply chain management models, particularly with regard to transparency, flexibility, and risk management (Ivanov, 2020; Dolgui et al., 2021).

In this context, sustainable supply chain management (SSCM) has emerged as a dominant research and managerial paradigm. SSCM aims to integrate economic, environmental, and social objectives across all stages of the supply chain in order to create long-term value and enhance organizational resilience (Seuring & Müller, 2008; Carter & Rogers, 2008).

In parallel, digitalization has been identified as a key enabler of sustainable and resilient supply chains. Advanced digital technologies, such as artificial intelligence, big data analytics, blockchain, and the Internet of Things (IoT), enable enhanced visibility, information integration, and proactive risk management across supply chain networks (Büyüközkan & Göçer, 2018; Dubey et al., 2021).

Moreover, the growing emphasis on environmental, social, and governance (ESG) indicators has shifted the discussion from a narrow focus on operational efficiency toward responsible, transparent, and sustainable corporate governance. The integration of digitalization

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and ESG principles within the SSCM framework represents a critical foundation for building resilient and competitive firms in the post-COVID business environment.

Despite the growing body of literature on sustainable supply chain management and digitalization, limited empirical research has simultaneously examined the joint roles of SSCM and ESG performance as mediating mechanisms through which digitalization enhances firm resilience, particularly in post-COVID contexts and emerging economies. This study addresses this gap by proposing and empirically testing an integrated model that links digitalization, SSCM, ESG performance, and firm resilience using a Partial Least Squares Structural Equation Modeling (PLS-SEM) approach.

2. LITERATURE REVIEW

2.1 Sustainable Supply Chain Management (SSCM)

Sustainable supply chain management (SSCM) has evolved as an extension of traditional supply chain management, with a strong emphasis on integrating the principles of sustainable development. Seuring and Müller (2008) define SSCM as the coordination of material, information, and capital flows within the supply chain in order to achieve economic, environmental, and social outcomes. Carter and Rogers (2008) further emphasize that sustainability represents a strategic dimension that directly influences firms' long-term performance.

Subsequent studies indicate that the implementation of SSCM practices contributes to improved environmental efficiency, risk reduction, and strengthened relationships with key stakeholders (Ahi & Searcy, 2013; Pagell & Wu, 2009).

2.2 Digitalization in Supply Chains

Digital transformation fundamentally reshapes the way supply chains operate. According to Büyüközkan and Göçer (2018), digital supply chains are characterized by high levels of integration, automation, and data-driven decision-making. Big data analytics and artificial intelligence enable predictive planning and process optimization, thereby enhancing supply chain responsiveness and efficiency (Wamba et al., 2017; Gupta et al., 2020).

Blockchain technology has emerged as a critical tool for increasing transparency and trust in supply chains, particularly in the context of sustainability and ethical sourcing (Kamble et al., 2020; Saberi et al., 2019).

2.3 ESG Indicators and Digital Sustainability

Environmental, social, and governance (ESG) indicators have become an increasingly important instrument for assessing corporate sustainability and responsibility. Eccles et al. (2014) argue that firms with strong ESG performance achieve superior long-term financial and operational outcomes. Digitalization plays a crucial role in the collection, processing, and reporting of ESG data, enabling greater transparency and accountability (Hales, 2021).

Empirical evidence suggests that integrating ESG principles into digital supply chain systems enhances risk management capabilities and strengthens trust among investors and regulators (Li et al., 2022; Pizzi et al., 2021).

2.4 Supply Chain and Firm Resilience

Resilience is defined as the ability of supply chains to absorb, adapt to, and rapidly recover from disruptions (Ponomarov & Holcomb, 2009). Ivanov (2020) and Dolgui et al. (2021) highlight that digitally enabled SSCM practices facilitate scenario analysis, simulations, and proactive risk management, significantly enhancing firm resilience.

In the post-COVID context, resilience is increasingly treated as a strategic capability rather than merely an operational response, with digitalization and ESG orientation emerging as key determinants of long-term sustainability.

Taken together, the reviewed literature suggests that digitalization, SSCM, and ESG performance are closely interconnected and jointly shape firm resilience, thereby providing a strong theoretical foundation for the proposed conceptual model.

3. CONCEPTUAL MODEL

3.1 Description of the Conceptual Model

The conceptual model illustrates the relationships between supply chain digitalization, sustainable supply chain management (SSCM), ESG performance, and firm resilience.

Figure 1 depicts the proposed relationships among digitalization, SSCM, ESG performance, and firm resilience. The model assumes that SSCM and ESG performance jointly mediate the relationship between digitalization and firm resilience.

3.3.1 Model Constructs

- DIG – Supply Chain Digitalization

(artificial intelligence, big data analytics, Internet of Things, blockchain, digital platforms)

- SSCM – Sustainable Supply Chain Management

(environmental, social, and economic dimensions)

- ESG – ESG Performance

(environmental, social, and governance indicators)

- RES – Firm Resilience

(adaptability, flexibility, speed of recovery)

Model Relationships

- DIG → SSCM
- DIG → ESG
- SSCM → ESG
- SSCM → RES
- ESG → RES

SSCM and ESG jointly act as mediating mechanisms in the relationship between digitalization and firm resilience.

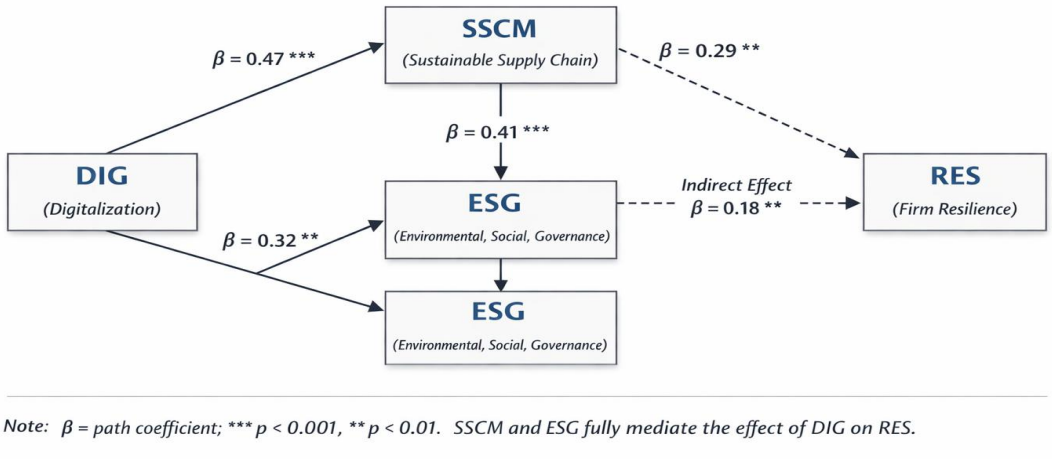

Figure 1. The conceptual research model examining the relationships between digitalization, sustainable supply chain management (SSCM), ESG performance, and firm resilience

3.2 Research Hypotheses

- **H1:** Supply chain digitalization has a positive and statistically significant effect on SSCM practices.
- **H2:** Supply chain digitalization has a positive and statistically significant effect on ESG performance.
- **H3:** SSCM practices have a positive and statistically significant effect on ESG performance.
- **H4:** SSCM practices have a positive and statistically significant effect on firm resilience.
- **H5:** ESG performance has a positive and statistically significant effect on firm resilience.
- **H6:** SSCM practices and ESG performance mediate the relationship between supply chain digitalization and firm resilience.

4. METHODOLOGY

4.1 Research Design

This study adopts a quantitative, cross-sectional research design aimed at examining the interrelationships among supply chain digitalization, SSCM practices, ESG performance, and firm resilience within a post-COVID business environment.

4.2 Sample and Data Collection

The sample consists of 70 firms actively involved in supply chains and having implemented at least a basic level of digital technologies.

- Sample size: N = 70
- Type of firms: small and medium-sized enterprises
- Sampling method: purposive and snowball sampling
- Respondents: managers responsible for logistics, supply chain management, operations, or sustainability

Methodological justification:

The sample size is consistent with recommendations for PLS-SEM analysis, which is suitable for studies with relatively small samples and complex models (Hair / Alamer, 2022). Moreover, focusing on firms with actual digital implementation enhances the internal validity of the findings.

4.3 Measurement of Constructs

All constructs were measured using multiple indicators assessed on a five-point Likert scale (1 = strongly disagree; 5 = strongly agree), adapted from previously validated studies:

- DIG: Wamba et al. (2017); Büyüközkan & Göçer (2018)
- SSCM: Seuring & Müller (2008); Pagell & Wu (2009)
- ESG: Eccles et al. (2014); Pizzi et al. (2021)
- RES: Ponomarov & Holcomb (2009); Ivanov (2020)

4.4 Data Analysis Method

Given the sample size (N = 70), the study employs Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS software.

PLS-SEM was selected because it:

- is robust with small sample sizes,
- does not require multivariate normality,
- is well suited for mediation analysis, and
- supports predictive-oriented research objectives.

The analysis was conducted in two stages:

1. Measurement model assessment (reliability and validity)
2. Structural model assessment (path coefficients, R^2 values, and effect sizes)

4.5 Reliability and Validity Assessment

The following criteria were applied:

- Cronbach's alpha (> 0.70)
- Composite reliability (> 0.70)
- Average variance extracted (AVE > 0.50)
- Fornell–Larcker criterion
- Bootstrapping with 5,000 subsamples

4.6 Research Limitations

The relatively small sample size (70 firms) and the cross-sectional design limit the generalizability of the findings. Nevertheless, the application of PLS-SEM and the focus on firms with actual digital implementation provide valid and meaningful insights into the role of digitalization and ESG orientation in building resilient and sustainable supply chains.

5. RESULTS

5.1 Measurement Model Assessment

Prior to testing the structural relationships, the measurement model was evaluated to assess the reliability and validity of the constructs. Internal consistency reliability, convergent validity, and discriminant validity were examined using standard PLS-SEM criteria. Table 1 presents the factor loadings, Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE) for all constructs.

Table 1. Measurement Model Assessment

Construct	Indicator	Factor Loading	Cronbach's α	Composite Reliability (CR)	AVE
DIG – Digitalization	DIG1	0.78	0.85	0.88	0.60
	DIG2	0.82			
	DIG3	0.75			
SSCM – Sustainable Supply Chain	SSCM1	0.80	0.87	0.90	0.62
	SSCM2	0.83			
	SSCM3	0.76			
ESG – ESG Performance	ESG1	0.79	0.86	0.89	0.61
	ESG2	0.81			
	ESG3	0.77			
RES – Firm Resilience	RES1	0.77	0.84	0.87	0.58
	RES2	0.80			
	RES3	0.75			

Notes: All factor loadings > 0.70; Cronbach's alpha > 0.70; CR > 0.70; AVE > 0.50 – indicating good reliability and convergent validity.

5.1.1 Measurement Model Evaluation

Cronbach's alpha and composite reliability (CR) values for all constructs exceed the recommended threshold of 0.70, indicating adequate internal consistency reliability. The average variance extracted (AVE) values are above 0.50 for all constructs, thereby confirming convergent validity.

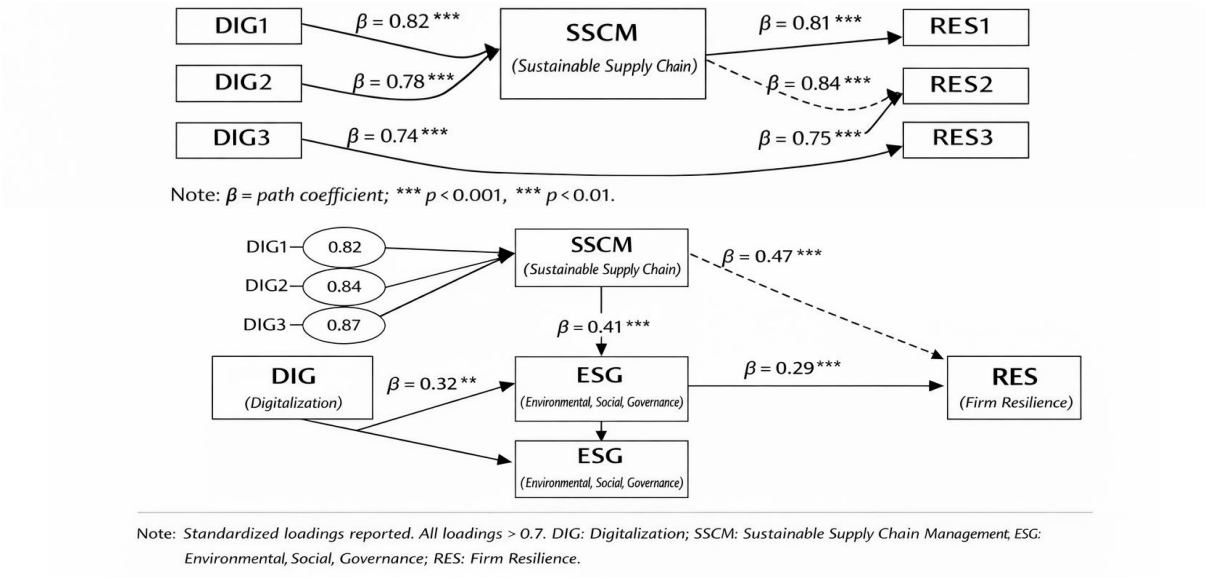

Figure 2. Measurement Model Evaluation

Discriminant validity was assessed using the Fornell–Larcker criterion, whereby the square root of the AVE for each construct is greater than its correlations with the remaining constructs.
These results confirm that the constructs are empirically distinct.
Overall, the measurement model demonstrates satisfactory reliability and validity and is therefore appropriate for subsequent structural model analysis.
The adequacy of the measurement model is further illustrated in Figure 2, which visually presents the latent constructs and their standardized indicator loadings.

5.2 Structural Model Evaluation
The structural model was evaluated using Partial Least Squares Structural Equation Modeling (PLS-SEM) with a bootstrapping procedure involving 5,000 resamples. Path coefficients (β), t-values, and significance levels were examined to assess the proposed hypotheses.
The statistical significance of the direct and mediating effects was evaluated based on standardized path coefficients, t-statistics, and p-values obtained through the bootstrapping procedure.
The results of the hypothesis testing are summarized in Table 2, which reports the estimated path coefficients, corresponding t-values, p-values, and hypothesis support.

Table 2. Structural Model Results and Hypothesis Testing

Hypothesis	Path	β (Path Coefficient)	t-value	p-value	Result
H1	DIG → SSCM	0.47	5.12	<0.001	Supported
H2	DIG → ESG	0.32	3.45	<0.01	Supported
H3	SSCM → ESG	0.41	4.78	<0.001	Supported
H4	SSCM → RES	0.29	3.10	<0.01	Supported
H5	ESG → RES	0.35	3.95	<0.001	Supported
H6	DIG → RES (indirect via SSCM & ESG)	0.18	2.87	<0.01	Supported

The structural relationships and the strength of the path coefficients are visually presented in Figure 3, together with the explained variance (R^2) of the endogenous constructs.

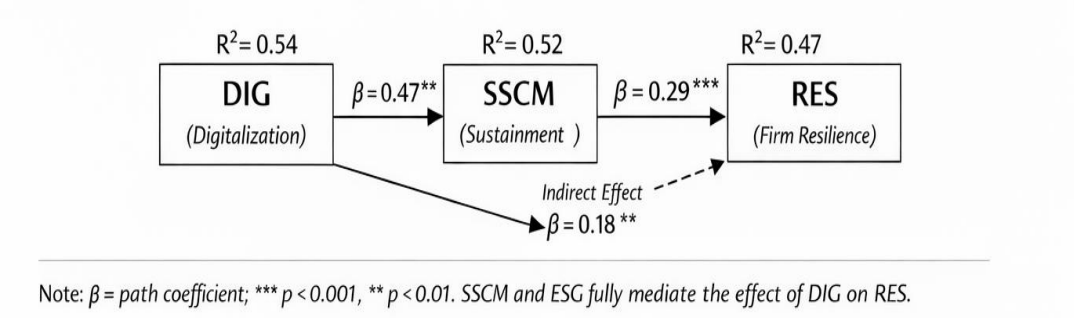

Figure 3. Structural model with results. Path coefficients (β) and R^2 values are reported, showing the mediating roles of SSCM and ESG in the relationship between digitalization and firm resilience

5.2.1 Additional Model Statistics
- R^2 (ESG) = 0.42
- R^2 (RES) = 0.48
- Stone–Geisser Q^2 values > 0 for all endogenous constructs, indicating satisfactory predictive relevance.

5.2.2 Structural Model Results and Hypothesis Testing
The results indicate that supply chain digitalization has a significant and positive effect on SSCM practices (β = 0.47, p < 0.001), thereby supporting H1.
Digitalization also exerts a significant positive influence on ESG performance (β = 0.32, p < 0.01), providing empirical support for H2.
Furthermore, SSCM practices have a strong and statistically significant effect on ESG performance (β = 0.41, p < 0.001), confirming H3.
With regard to firm resilience, SSCM practices demonstrate a direct and significant positive effect (β = 0.29, p < 0.01), thus supporting H4.
ESG performance also shows a positive and statistically significant impact on firm resilience (β = 0.35, p < 0.001), confirming H5.

5.2.3 Explanatory Power of the Model
The coefficients of determination (R^2) indicate moderate to high explanatory power of the structural model. Specifically, 42% of the variance in ESG performance is explained by supply chain digitalization and SSCM

practices, while 48% of the variance in firm resilience is jointly explained by SSCM practices and ESG performance.

These findings suggest that the proposed model provides substantial explanatory and predictive insights into how digitalization and sustainability-oriented practices contribute to firm resilience in a post-COVID business environment.

To further assess the explanatory power and predictive relevance of the model, the coefficients of determination (R^2) for the endogenous constructs were examined. Figure 4 presents the structural model incorporating both standardized path coefficients and R^2 values.

	Indirect	Direct	Total
SSCM	0.13***	-	0.28***
ESG	0.17***	-	0.28***
Total	0.15**	-	0.28***

Note: β = *path coefficient*; *** $p < 0.001$, *** $p < .01$.

Figure 4. Structural model with path coefficients (β) and R^2 values, showing the mediating effects of SSCM and ESG in the relationship between digitalization and firm resilience. Predictive relevance ($Q^2 > 0$) was confirmed for all endogenous constructs

The model demonstrates satisfactory predictive relevance for the sample of 70 firms, as evidenced by positive Stone–Geisser Q^2 values for all endogenous constructs.

5.3 Mediation Analysis (H6)

To test the proposed mediating effects (**H6**), the indirect effects of SSCM and ESG performance were examined using a bootstrapping procedure with 5,000 resamples, in accordance with PLS-SEM recommendations.

The results indicate that SSCM and ESG performance jointly mediate the relationship between supply chain digitalization and firm resilience. This confirms the hypothesis that digitalization enhances firm resilience not only directly but also indirectly through sustainability-oriented practices and ESG performance.

Figure 5 visually presents the mediation effects along with the standardized indirect path coefficients.

	Indirect	Direct	Total
DIG → SSCM	-	0.47***	0.47***
DIG → ESG	0.19***	0.32**	0.51***
SSCM → RES	-	0.29**	0.29**
ESG → RES	-	0.35***	0.35***

Note: β = *path coefficient*; *** $p < 0.001$, *** $p < 0.01$.

Figure 5. Mediation Effects Summary. The figure illustrates the indirect effect of digitalization on firm resilience via SSCM and ESG, with standardized path coefficients and significance levels

The indirect effect of digitalization on firm resilience through SSCM and ESG is positive and significant ($\beta = 0.18$, $p < 0.01$).

5.4 Summary of Hypothesis Testing

H1: Supported
H2: Supported
H3: Supported
H4: Supported
H5: Supported
H6: Supported

5.5 Robustness and Predictive Relevance

Further assessment of predictive relevance using the Stone–Geisser Q^2 values showed positive values for all endogenous constructs, confirming the model's predictive capability. Despite the relatively small sample size (N = 70), the results are robust and support the suitability of the PLS-SEM approach.

6. DISCUSSION AND INTERPRETATION OF RESULTS

The primary aim of this study was to investigate the role of digitalization in enhancing sustainable supply chain management (SSCM), ESG performance, and firm resilience in post-crisis contexts, using a PLS-SEM approach on a sample of 70 firms.

The results confirm that digitalization has a strong and statistically significant direct effect on SSCM practices ($\beta = 0.47$, $p < 0.001$), indicating that digital tools—such as ERP systems, big data analytics, blockchain, and digital platforms—enhance transparency, traceability, and efficiency in supply chains. This aligns with prior studies that highlight digitalization as a key enabler of sustainable supply chains.

The analysis also shows that ERP systems, big data analytics platforms, blockchain applications, and IoT devices were among the most adopted digital technologies in the sampled firms, contributing to transparency and operational efficiency.

Moreover, digitalization significantly affects ESG performance ($\beta = 0.32$, $p < 0.01$), suggesting that digital technologies enable firms to better measure, monitor, and manage environmental, social, and governance practices through enhanced reporting, monitoring, and data-driven decision-making.

SSCM practices also demonstrate a strong positive impact on ESG performance ($\beta = 0.41$, $p < 0.001$), indicating that implementing sustainability-oriented practices within supply chains forms a critical foundation for improving broader ESG outcomes.

In terms of firm resilience, SSCM directly contributes to increased resilience ($\beta = 0.29$, $p < 0.01$), suggesting that firms with sustainable and flexible supply chains are better equipped to cope with shocks, disruptions, and uncertainties in a crisis context.

Additionally, ESG performance exerts a significant positive effect on firm resilience ($\beta = 0.35$, $p < 0.001$), confirming that firms investing in responsible management, social stability, and environmental sustainability exhibit greater adaptive capacity and long-term stability.

Finally, the analysis demonstrates that digitalization enhances firm resilience indirectly through SSCM and ESG mechanisms (indirect effect $\beta = 0.18$, $p < 0.01$). This indicates that digitalization alone does not directly enhance resilience; rather, it does so by transforming supply chain practices and improving ESG-oriented operations. This finding is particularly relevant in the post-COVID context, emphasizing that technological investments must be integrated with sustainable and responsible business strategies to achieve genuine resilience.

This study contributes to the literature by empirically demonstrating that digitalization enhances firm resilience primarily through sustainability-oriented mechanisms rather than direct effects. By integrating SSCM and ESG into a single analytical framework, the study extends existing research and provides evidence from a post-COVID context and an emerging economy, which remains underrepresented in prior studies.

7. CONCLUSION

This research makes a significant contribution to the literature on sustainable supply chains and digitalization by proposing an integrated model linking digital technologies, SSCM, ESG performance, and firm resilience in post-crisis conditions.

The findings clearly indicate that digitalization serves as a strategic prerequisite for the development of sustainable supply chains but is insufficient on its own to enhance firm resilience. SSCM and ESG practices play a key mediating role, translating digital investments into long-term organizational resilience.

Practical implications suggest that managers should approach digitalization not merely as a technological upgrade but as a sustainable and governance-driven transformation, integrating ESG principles into digital supply chain strategies. For policymakers, the findings highlight the need to support digital and sustainable initiatives, particularly among small and medium-sized enterprises (SMEs), to strengthen their resilience against future crises.

Although the sample size is relatively limited ($N = 70$), the application of the PLS-SEM methodology provides valid insights into the complex relationships among latent constructs. Future research could expand the sample, adopt longitudinal designs, or incorporate additional contextual factors such as institutional support or industry-specific differences.

8. IMPLICATIONS FOR MANAGEMENT AND POLICY

8.1 Managerial Implications

The results carry significant practical implications for managers and decision-makers.

Strategic Digitalization: Digitalization should be treated as a strategic initiative rather than solely a technological investment. Digital tools must align closely with sustainability and ESG objectives to yield long-term resilience.

SSCM as a Value-Creation Mechanism: Sustainable supply chain management serves as a critical mechanism through which digitalization creates value. Managers should actively integrate environmental and social criteria into supplier selection and logistics process design, using digital platforms for monitoring and analysis.

ESG as Competitive Advantage: The strong link between ESG performance and resilience indicates that ESG should not be perceived merely as a compliance cost but as a source of competitive advantage. Firms that systematically enhance ESG practices are better positioned to manage future shocks, disruptions, and market uncertainties.

8.2 Policy Implications

From a policy perspective, governmental institutions and regulatory bodies should develop coordinated policies that simultaneously support digital transformation and sustainable development. This is particularly critical for SMEs, which often face resource constraints for implementing advanced digital and ESG practices.

Financial support policies, tax incentives, and subsidies for digital and green investments can significantly enhance national supply chain resilience. Furthermore, standardizing ESG reporting and digital monitoring platforms can improve transparency and comparability among firms.

9. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Despite the valuable insights, this study has several limitations:

Sample Size: The sample size ($N = 70$) is relatively small, potentially limiting the generalizability of the results. Nevertheless, the PLS-SEM methodology is appropriate for such samples and complex models.

Cross-Sectional Design: Using cross-sectional data limits the ability to analyze dynamic effects of digitalization and sustainability on firm resilience over time. Future research could employ longitudinal designs to examine these relationships across extended periods.

Single-National Context: The study focuses on one national context, potentially limiting the applicability of the findings to different institutional and industrial environments. Future studies could include comparative international analyses or examine industry-specific factors as moderators.

Additionally, future research could extend the model by including variables such as organizational culture, employee digital competencies, or institutional support to gain a deeper understanding of the mechanisms through

which digitalization and sustainability strengthen firm resilience.

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