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Impact of knowledge sharing, IT support, and innovation on supply chain sustainability with uncertainty moderation

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This study analyzes the relationships between knowledge sharing culture, information technology support, and process innovation on supply chain sustainability in Indonesia's digital printing SMEs, with market uncertainty as a moderating variable. Employing an explanatory approach, the research utilizes a cross-sectional survey involving 225 SME owners. Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The findings reveal that knowledge sharing culture has a significant positive impact on both process innovation and supply chain sustainability. Conversely, information technology support negatively affects these two variables. Process innovation positively contributes to supply chain sustainability, albeit with a small effect. Market uncertainty strengthens supply chain sustainability but weakens the relationship between process innovation and sustainability. The mediating role of knowledge sharing culture through process innovation highlights a critical pathway for enhancing supply chain sustainability. This study offers theoretical and practical implications regarding the importance of knowledge sharing culture and process innovation, alongside challenges in technology adoption. The study's limitations include its cross-sectional approach and focus on digital printing SMEs in Indonesia. Future research is recommended to adopt a longitudinal approach to explore dynamic changes in this context. The novelty of this study lies in its integrated understanding of factors influencing supply chain sustainability amid market uncertainty.

1. Introduction

Supply chain sustainability has become a critical issue in the modern era, especially for small and medium enterprises (SMEs) facing external pressures to adopt sustainability principles in increasingly competitive markets. This concept aims to minimize the negative impact of businesses on the environment and society while ensuring operational continuity and sustainable economic growth (Olanrewaju et al., 2020; Ten, 2022). In the context of Indonesia's digital printing SMEs, supply chain sustainability is particularly relevant due to demands for more efficient, environmentally friendly, and market-responsive supply chain practices (Sari et al., 2023).

The COVID-19 pandemic has created significant challenges for SMEs worldwide, including those in Indonesia. Disruptions in supply chains, demand fluctuations, and resource constraints have posed major operational hurdles for digital printing SMEs (Bartik et al., 2020; Kuckertz et al., 2020). However, this crisis has also opened opportunities for innovation through better adaptation processes. Digital printing SMEs have begun adopting information technology and fostering a knowledge

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sharing culture to enhance supply chain efficiency and strengthen their competitiveness in both domestic and global markets (Lin et al., 2024; Chen et al., 2022).

In this context, process innovation plays a central role as a mediating variable connecting knowledge sharing culture and information technology support to supply chain sustainability. Process Innovation enables digital printing SMEs to translate insights gained from knowledge sharing culture and information technology into concrete solutions that improve operational efficiency, reduce waste, and ensure supply chain sustainability amidst market uncertainty (Susitha et al., 2024; Miklian & Hoelscher, 2022).

Additionally, the success of process innovation in supporting supply chain sustainability is significantly influenced by market uncertainty. Market uncertainty, such as changing customer demands and fluctuations in raw material prices, can affect SMEs' ability to implement sustainable supply chain strategies (Bourletidis & Triantafyllopoulos, 2014; Karmaker et al., 2023).

This study aims to analyze how knowledge sharing culture, information technology support, and process innovation interact to support supply chain sustainability in Indonesia's digital printing SMEs. Furthermore, market uncertainty will be examined as a moderating factor influencing the relationship between process innovation and supply chain sustainability (Qu & Liu, 2022; Canh et al., 2019; Tiwari et al., 2024).

This research contributes theoretically by integrating the concepts of knowledge sharing culture, information technology support, and process innovation into the context of SME supply chain sustainability. Practically, the findings are expected to provide guidance for digital printing SMEs in Indonesia to enhance supply chain resilience, adapt to market uncertainties, and support sustainable economic growth.

2. Literature Review and Hypotheses Development

The digital printing SME industry in Indonesia has experienced significant growth in recent years. This growth has been driven by advances in information technology, increasing demand for personalized products, and shifting consumer preferences toward faster and more efficient services. However, this sector faces complex challenges, including volatile market dynamics, intense competition, and the need to enhance supply chain sustainability amidst growing environmental and social pressures (Gazi et al., 2024).

In the context of supply chain sustainability, several key factors play a crucial role: Knowledge sharing culture, information technology support, and process innovation. These factors interact to create a more adaptive, efficient, and sustainable supply chain (Al et al., 2019; Zhao et al., 2023).

Knowledge sharing culture is a critical factor that fosters collaboration and innovation within the supply chain. By sharing knowledge, ideas, and experiences, stakeholders in the digital printing SME ecosystem can enhance production and operational efficiency. Knowledge sharing culture also facilitates the adoption of process innovation by creating an open and collaborative work environment where business actors can learn from one another and accelerate the implementation of new solutions (Alharbi & Aloud, 2024; Chen et al., 2022).

Information technology support is essential for improving supply chain sustainability. Information Technology enables real-time supply chain data management, accelerates decision-making, and enhances transparency across the supply chain. Moreover, information technology fosters a knowledge-sharing culture by providing efficient digital collaboration platforms. With Information Technology support, SMEs can optimize process innovation to sustain supply chains in dynamic market conditions (Alma Çallı et al., 2022; Latan et al., 2024).

Process innovation serves as a mediating factor connecting knowledge sharing culture and information technology support to supply chain sustainability. Through process innovation, businesses can translate knowledge and technology into concrete solutions such as production efficiency, waste reduction, and enhanced competitiveness. In the digital printing SME industry, process innovation plays a vital role in reducing operational costs and improving customer satisfaction through better products and services (Oliveira et al., 2024; Miklian & Hoelscher, 2022).

Market uncertainty acts as a moderating factor that can either strengthen or weaken the influence of process innovation on supply chain sustainability. For example, changes in customer preferences, fluctuations in raw material prices, or disruptions in the supply chain may affect SMEs' ability to implement process innovation effectively. Adapting to market uncertainty is thus a critical element in sustainable supply chain strategies (Al Dhaheri et al., 2024; Bourletidis & Triantafyllopoulos, 2014).

By integrating Knowledge sharing culture, information technology support, and process innovation, SMEs in the digital printing sector can build more resilient and sustainable supply chains. This study aims to provide theoretical insights into how these factors interact and how market uncertainty moderates the relationship between process innovation and supply chain sustainability. Additionally, it offers practical contributions to help Indonesian SMEs address supply chain challenges, enhance competitiveness, and support sustainable economic growth.

To address the research problem, this study proposes the following hypotheses:

H1: *Knowledge sharing culture positively influences process innovation.* A knowledge sharing culture fosters a collaborative environment that enables organizations to develop innovative solutions more effectively (Capatina et al., 2024). Alharbi and Aloud (2024) highlight that a culture of sharing knowledge enhances teamwork and accelerates innovation. Similarly, Lin et al. (2024) emphasize that knowledge sharing culture strengthens team interactions within technology-based small and medium enterprises, facilitating more adaptive and market-relevant process innovations.

H2: *Information technology support positively impacts process innovation.* Information technology support plays a critical role in driving Process Innovation (Lin et al., 2025). Vázquez Meléndez et al. (2025) reveal that the strategic use of information technology support enhances operational efficiency and fosters process innovation, particularly in complex supply chain contexts. (Latan et al., 2024) further demonstrate that information technology support enables small and medium enterprises to optimize data utilization, streamline decision-making, and promote sustainability through integrated process innovations.

H3: *Knowledge sharing culture positively affects supply chain sustainability.* A Knowledge Sharing Culture promotes collaboration and innovation, thereby enhancing operational efficiency and improving the resilience of the supply chain (Lin et al., 2024; Ahmad & Karim, 2019).

H4: *Information technology support has a positive effect on supply chain sustainability.* Information technology support enhances transparency, accelerates decision-making processes, and optimizes supply chain management (Al et al., 2019; Alma Çallı et al., 2022).

H5: *Process innovation positively contributes to supply chain sustainability.* By implementing process innovations, businesses can reduce waste, improve operational efficiency, and shorten production cycles, which collectively support sustainable operations (Costantini et al., 2017; Miklian & Hoelscher, 2022; Lin et al., 2024).

H6: *Market uncertainty moderates the relationship between process innovation and supply chain sustainability.* Market uncertainty, such as fluctuating raw material prices or shifting consumer preferences, encourages rapid and adaptive Process Innovations that enhance competitiveness and supply chain resilience (Bourletidis & Triantafyllopoulos, 2014).

These hypotheses aim to provide both theoretical and practical insights into how digital printing small and medium enterprises in Indonesia can address supply chain challenges, enhance their competitiveness, and achieve sustainable economic growth. The proposed conceptual framework is presented in Fig. 1.

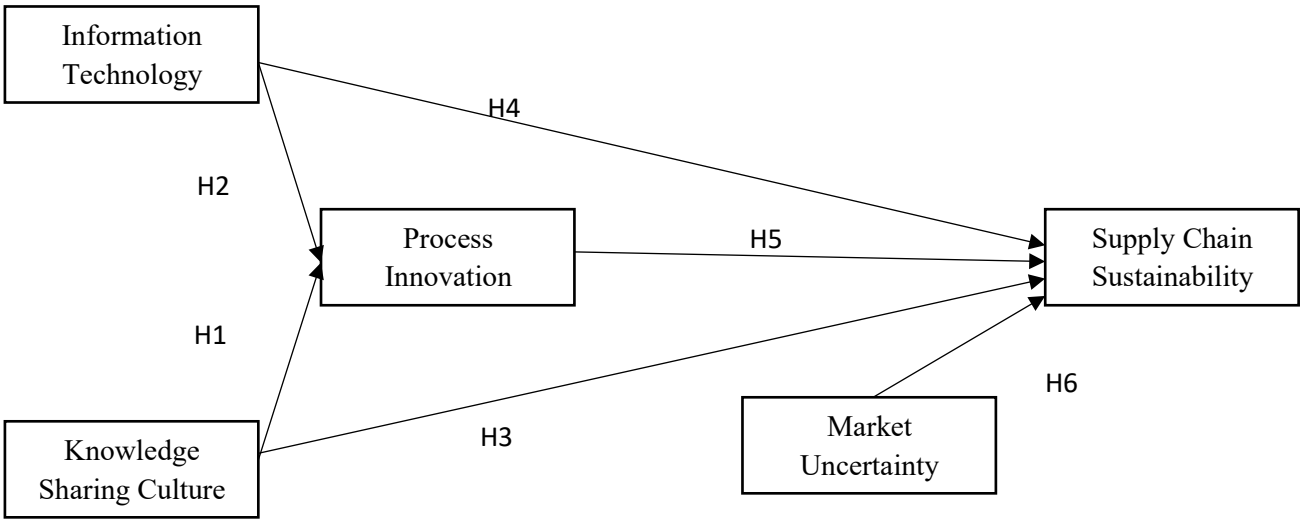

Fig. 1. Conceptual Framework

3. Research Method

3.1. Research Design

This study employs an explanatory approach to analyze the relationships between knowledge sharing culture, information technology support, and process innovation on supply chain sustainability, with market uncertainty serving as a moderating variable. The research is designed to test the hypotheses using cross-sectional data, which is particularly suitable for exploring relationships between variables within a specific period (Harrison et al., 2020). This approach was chosen for its efficiency in capturing current conditions without requiring extensive resources, as would be necessary in longitudinal studies (Gomm, 2008). However, it is acknowledged that this approach has limitations in capturing long-term dynamics, making longitudinal studies a recommended avenue for future research to understand changes in these factors over time.

In the context of the digital printing small and medium enterprises (SMEs) industry in Indonesia, this study focuses on the roles of knowledge sharing culture and information technology support in fostering supply chain sustainability through process innovation. Knowledge sharing culture encourages collaboration and the sharing of insights within the supply chain ecosystem, such as sharing information about new technologies or best practices in material management. Information technology support, on the other hand, facilitates real-time processing of supply chain data, enhances decision-making, and provides efficient platforms for collaboration.

Process innovation acts as a mediating variable connecting knowledge sharing culture and information technology support to supply chain sustainability. By integrating knowledge and technological support, process innovation enables companies to develop efficient solutions such as waste reduction, improved production efficiency, and adaptation to dynamic customer preferences (Miklian & Hoelscher, 2020). Furthermore, Market Uncertainty serves as a moderating variable influencing the relationship between Process Innovation and Supply Chain Sustainability. For instance, fluctuations in raw material prices or changes in consumer demands can amplify the necessity for Process Innovation as an adaptive response to these challenges (Bourletidis & Triantafyllopoulos, 2014).

This study provides an integrated framework for understanding how knowledge sharing culture, information technology support, and process innovation contribute to supply chain sustainability amidst market uncertainty. Additionally, this approach underscores the critical role of process innovation in mediating the relationship between knowledge sharing culture and information technology support with supply chain sustainability. Future studies could adopt a longitudinal approach to explore long-term changes in these dynamics and delve deeper into the moderating role of Market Uncertainty in the supply chain context of digital printing SMEs in Indonesia.

3.2. Sampling Strategy

This study employs a purposive sampling method to target 225 small and medium-sized enterprise (SME) owners in the digital printing sector in Indonesia. Respondents are selected based on their involvement in decision-making related to innovation, resource management, and supply chain strategy. The selection criteria include a minimum age of 17 years to ensure legal eligibility for business operations and a minimum company age of 2 years to guarantee operational stability and relevant business management experience. Data analysis is conducted using the Partial Least Squares Structural Equation Modeling (PLS-SEM) method, chosen for its capability to handle complex relationships among variables and its suitability for moderate sample sizes. Following the guidelines of (Hair & Hair, 2010), the sample size of 225 respondents is considered adequate to ensure valid and reliable results.

3.3. Data Collection

Data collection was conducted from August to November 2024 using a Likert-scale questionnaire to analyze the relationships among knowledge sharing culture, information technology support, process innovation (as a mediating variable), and supply chain sustainability, with market uncertainty as a moderating variable in digital printing SMEs in Indonesia.

The questionnaire was developed based on prior literature to ensure the validity and relevance of the indicators used. Indicators for knowledge sharing culture include employee collaboration, continuous learning, sharing of ideas and experiences, use of technology for knowledge sharing, employee trust, involvement in innovative discussions, rewards for knowledge sharing, and cross-functional knowledge transfer (Toufighi et al., 2024). Indicators for Information Technology Support cover the availability of adequate technology tools, ease of information access, technology training, efficiency of IT-based systems, and integration of technology into business operations (Berkovich & Hassan, 2024). For process innovation, indicators include operational efficiency improvements, development of new production methods, reduction of process time, adoption of cutting-edge technology, and optimization of business processes (Fosu et al., 2024). Indicators for supply chain sustainability include resource efficiency, environmental impact reduction, operational flexibility, collaboration with supply chain partners, and adaptability to market changes (Tang et al., 2024).

Challenges in data collection, such as time constraints and the operational activities of respondents, were addressed by scheduling questionnaire completions and interviews at flexible times convenient for the respondents (Harrison et al., 2020). A pilot test was conducted to ensure clarity and understanding of each questionnaire item, as recommended by (Gomm, 2008). To maintain data quality, the questionnaire was designed to be concise while still encompassing relevant indicators, following the guidelines of (Hair et al., 2019).

This approach aims to uncover how knowledge sharing culture and information technology support drive process innovation, which in turn enhances supply chain sustainability in the face of market uncertainty. The study is expected to provide strategic insights for digital printing SMEs in managing market uncertainty through strengthened innovation and supply chain collaboration.

3.4. Data Analysis Techniques

The data analysis in this study employs the Partial Least Squares Structural Equation Modeling (PLS-SEM) method, which is suitable for complex models, limited sample sizes, and non-normal data distributions (Hair et al., 2020). PLS-SEM is used to examine the relationships among knowledge sharing culture, information technology support, and process innovation on supply chain sustainability, with process innovation serving as a mediating variable and market uncertainty as a moderating variable.

The measurement model is evaluated by testing convergent validity, discriminant validity, and instrument reliability. Convergent validity is assessed using the Average Variance Extracted (AVE), with a minimum value > 0.5 (Henseler et al., 2015), while discriminant validity is evaluated using the Fornell-Larcker criterion and Heterotrait-Monotrait ratio, with values < 0.85 indicating good construct discrimination (Henseler et al., 2015). Reliability is measured using Composite Reliability and Cronbach's Alpha, with values > 0.7 considered acceptable.

The structural model is assessed by examining path coefficients to determine the strength and direction of relationships among variables. Significance testing is conducted using bootstrapping with 5,000 resamples, where T-values > 1.96 at a 95% confidence level indicate significance (Hair et al., 2013). The model's predictive power is evaluated using the coefficient of determination (R^2) to measure model strength, predictive relevance (Q^2) through Stone-Geisser's test for out-of-sample predictions, and effect size (f^2) to assess the relative contribution of each variable.

This approach provides a robust framework for understanding how knowledge sharing culture, information technology support, and process innovation influence supply chain sustainability, while considering the moderating effect of market uncertainty. By focusing on digital printing small and medium-sized enterprises in Indonesia, this study offers insights into strategies for enhancing operational sustainability in dynamic environments.

4. Results

4.1. Background Socio-Demographic Statistics

Table 1
Respondent Characteristics

Information	N	%	Information	N	%	Information	N	%
Gender			Education			Early Years		
Man	156	69.5	Primary	16	7.5	2–10 Years	91	40.3
Woman	69	30.5	Secondary	62	27.5	>10 Years	134	59.7
Amount	225	100.0	Bachelor	106	47.2	Amount	225	100.0
Age			Master’s	30	13.5	Employees		
17–34	66	29.4	Doctorate	4	1.8	< 10	46	20.4
35–52	98	43.7	Others	26	11.5	10–49	172	76.5
53+	61	26.9	Amount	225	100.0	50–249	7	3.1
Amount	225	100.0				Amount	225	100.0

Source: Data processed

Table 1 outlines the demographics of respondents in this study. The majority are male (69.5%), with females comprising 30.5%. Most digital printing SME owners in Indonesia hold a bachelor’s degree (47.2%), followed by secondary education (27.5%) and master’s degrees (13.5%), while fewer have a primary education (7.5%), doctoral degrees (1.8%), or other qualifications (11.5%).

In terms of age, respondents are primarily in the productive age range of 35–52 years (43.7%), followed by 17–34 years (29.4%) and 53 years and above (26.9%). Over half of the SMEs have operated for more than 10 years (59.7%), with the remaining 40.3% in operation for 2 to 10 years.

Regarding workforce size, most SMEs employ 10–49 workers (76.5%), while 20.4% have fewer than 10 employees, and 3.1% employ 50–249 workers. Overall, the SMEs in this study are well-established, led by well-educated, productive-age owners, and operate with small to medium-sized teams.

4.2. Measurement Model Assessments

Based on Table 2, the results of the measurement model assessment indicate that all variables in this study meet the criteria for convergent validity and reliability. The Average Variance Extracted (AVE) values for all variables are greater than 0.50,

indicating that each variable explains more than 50% of the variance in its indicators. Additionally, the Cronbach's Alpha and Composite Reliability (CR) values for each variable exceed 0.70, demonstrating good internal consistency in the measurements.

Table 2
Measurement Model Testing Convergent Validity, Composite Reliability and Cronbach's Alpha

Variable	λ	Cronbach's α	rho_A	CR	AVE
Knowledge Sharing Culture (KSC)		0.922	0.934	0.941	0.763
KSC1	0.841				
KSC2	0.839				
KSC3	0.874				
KSC4	0.736				
KSC5	0.811				
Information Technology (IT)		0.957	0.958	0.967	0.853
IT1	0.952				
IT2	0.869				
IT3	0.919				
IT4	0.941				
IT5	0.935				
Process Innovation (PI)		0.917	0.924	0.939	0.754
PI1	0.762				
PI2	0.920				
PI3	0.926				
PI4	0.883				
PI5	0.841				
Market Uncertainty (MU)		0.985	0.985	0.988	0.942
MU1	0.972				
MU2	0.977				
MU3	0.970				
MU4	0.981				
MU5	0.952				
Supply Chain Sustainability (SCS)		0.932	0.933	0.949	0.788
SCS1	0.921				
SCS2	0.884				
SCS3	0.840				
SCS4	0.934				
SCS5	0.855				
Moderating MU & PI	1.000	1.000	1.000	1.000	1.000

Source: Data processed

Knowledge Sharing Culture, Information Technology Support, Process Innovation, Market Uncertainty, and Supply Chain Sustainability have indicators with high loading factors (>0.70), signifying significant relationships between the indicators and their respective variables. The moderating variables (Market Uncertainty and Process Innovation) show perfect scores (AVE, Cronbach's Alpha, and CR = 1.000), indicating excellent measurement strength. Overall, these results demonstrate that the measurement model in this study is valid and reliable, making it suitable for further structural analysis to evaluate the relationships between the variables in this research.

4.3. Measurement Model Assessments

Table 3
Discriminant Validity

Variable	IT	KSC	MU	Moderating MU & PI	PI	SCS
Fornell-Larcker Criterion						
IT	0.924					
KSC	0.433	0.873				
MU	0.422	0.970	0.971			
Moderating MU & PI	-0.098	-0.041	-0.025	1.000		
PI	-0.117	0.789	0.777	0.029	0.869	
SCS	0.095	0.862	0.872	-0.147	0.861	0.888
Heterotrait-Monotrait Ratio (HTMT)						
IT						
KSC	0.479					
MU	0.435	0.818				
Moderating MU & PI	0.100	0.090	0.026			
PI	0.123	0.842	0.818	0.063		
SCS	0.173	0.824	0.811	0.152	0.830	

Based on Table 3, the discriminant validity analysis, using the Fornell-Larcker Criterion and the Heterotrait-Monotrait Ratio (HTMT), confirms that all constructs in this model meet the criteria for discriminant validity. According to the Fornell-Larcker Criterion, the square root of the Average Variance Extracted (AVE) for each construct is greater than the correlations between that construct and any other constructs, indicating that each construct has clear uniqueness. Furthermore, the HTMT analysis shows that the heterotrait-monotrait ratio values for all construct pairs are below the conservative threshold of 0.85 and the liberal threshold of 0.90. These results confirm that there is no significant conceptual overlap between the constructs in the model, thereby achieving discriminant validity. Consequently, this model is ready for further analysis, such as hypothesis testing.

4.4. Structural Model Testing Results

Test the Inner Model. Structural models focus on hypothesized relationships or paths between variables. The results of the inner model testing can be seen in Fig. 2.

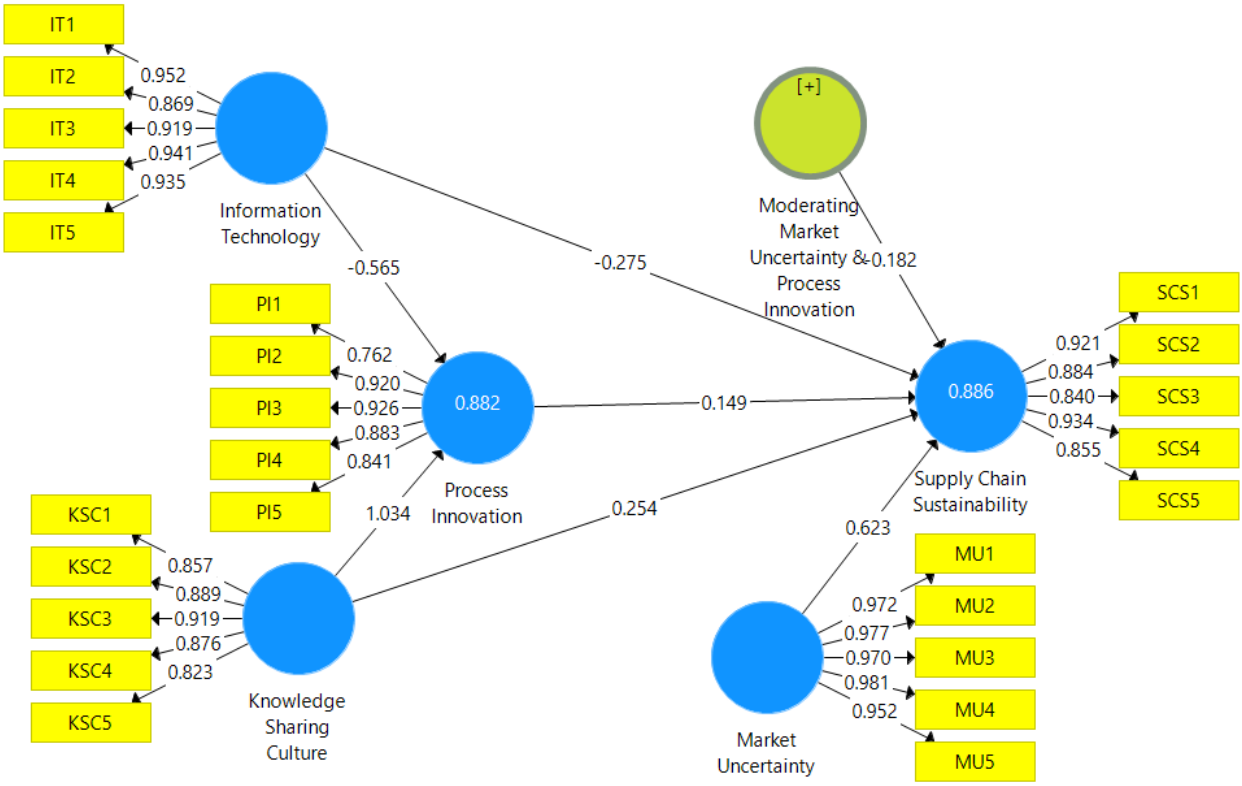

Fig. 2. Structural Model

Based on Fig. 2, the results of the Partial Least Squares Structural Equation Modeling (PLS-SEM) analysis illustrate the relationships between latent variables and their indicators. Latent variables such as IT, KSC, MU, PI, and SCS have indicators with loading factors above 0.7, indicating good convergent validity.

The relationships between latent variables show that KSC has the strongest influence on PI (1.034) and also positively contributes to SCS (0.254). In contrast, IT has a negative influence on PI (-0.565) and SCS (-0.275). Additionally, MU has a positive direct contribution to SCS (0.623).

The moderating effect between MU and PI on SCS is relatively small (0.182). The high R^2 values for PI (88.2%) and SCS (88.6%) indicate that the model has very strong predictive capability.

Overall, the diagram emphasizes the importance of KSC in driving PI and SCS, although the negative effects of IT warrant further attention.

4.5. Hypothesis Testing Results

The results of hypothesis testing in Table 4 show that all relationships in the model are statistically significant, with P-values < 0.05. KSC has the strongest positive influence on PI (1.034, $P = 0.000$) and also supports SCS (0.254, $P = 0.016$). In contrast,

IT shows a significant negative influence on both PI (-0.565, P = 0.000) and SCS (-0.275, P = 0.000), indicating challenges in its implementation.

Table 4
Hypothesis Testing

Variable	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values	Decision
Direct Effects						
KSC -> PI	1.034	1.033	0.043	23.947	0.000	Significant
IT -> PI	-0.565	-0.563	0.038	14.905	0.000	Significant
KSC -> SCS	0.254	0.249	0.105	2.411	0.016	Significant
IT -> SCS	-0.275	-0.270	0.047	5.872	0.000	Significant
PI -> SCS	0.149	0.155	0.072	2.062	0.039	Significant
MU -> SCS	0.623	0.621	0.097	6.446	0.000	Significant
Indirect Effects (Mediating)						
IT -> PI -> SCS	-0.084	-0.087	0.041	2.048	0.041	Significant
KSC -> PI -> SCS	0.154	0.160	0.075	2.038	0.042	Significant
Effects Moderating						
Moderating MU & PI -> SCS	-0.182	-0.182	0.026	6.986	0.000	Significant

Source: Data processed

PI contributes positively to SCS (0.149, P = 0.039), although its effect is relatively small. MU has a strong positive impact on SCS (0.623, P = 0.000), but it weakens the relationship between PI and SCS through moderation (-0.182, P = 0.000).

Regarding the mediating effect, KSC influences SCS indirectly through PI (0.154, P = 0.042), showing that PI is a crucial pathway to enhancing SCS. In contrast, the mediating effect of IT remains negative (-0.084, P = 0.041).

Overall, these findings highlight the importance of KSC and PI in driving SCS, especially amidst MU. However, the implementation of IT requires better management to mitigate its negative impact.

Table 5
Presents the outcomes for Koefisien Determinasi (R^2) and Relevansi Prediktif (Q^2)

Variabel	R^2	Q^2
PI	0.882	0.879
SCS	0.886	0.879

Source: Data processed

Based on Table 5, the model demonstrates excellent predictive capability, as indicated by the Determination Coefficient (R^2) and Predictive Relevance (Q^2) values. The latent variable PI has an R^2 value of 0.882, meaning that 88.2% of the variance in PI is explained by KSC and IT. The latent variable SCS has an R^2 value of 0.886, indicating that 88.6% of the variance in SCS is explained by PI, KSC, IT, MU, and the moderating effects.

The high Q^2 values for PI (0.879) and SCS (0.879) show that the model has strong predictive relevance, meaning that the predictions of latent variable performance from the independent variables are highly accurate.

Overall, the high R^2 and Q^2 values suggest that this model is effective in explaining and predicting the relationships between variables, particularly in the context of PI and SCS.

Table 6
Presents the outcomes for f Square (f^2)

Variable	IT	KSC	MU	Moderating MU & PI	PI	SCS
IT					2.190	0.166
KSC					7.331	0.025
MU						0.198
Moderating MU & PI						0.200
PI						0.022
SCS						

Source: Data processed

The f^2 values in Table 6 reveal the strength of the relationships between various variables. IT has a strong influence on MU, with an f^2 value of 2.190, indicating a significant impact. KSC also demonstrates a strong influence on MU ($f^2 = 7.331$), highlighting the importance of this culture in shaping market dynamics. However, the influence of KSC on the moderation between MU and PI is very small ($f^2 = 0.025$), indicating a limited role in this interaction. Meanwhile, the relationship between MU and PI shows a small to moderate influence ($f^2 = 0.198$), suggesting an existing influence, but not a dominant one. The moderating effect of MU and PI on SCS also shows a small to moderate influence ($f^2 = 0.200$). Finally, PI appears to have a very small influence on SCS, with an f^2 value of 0.022. These results suggest that while some variables, such as IT and KSC, have a strong impact, others, like PI and its effect on sustainability, have a much smaller influence.

5. Discussion

5.1. Direct Effects

The results of this study indicate that knowledge sharing culture and process innovation play a significant role in enhancing supply chain sustainability in digital printing Small and Medium Enterprises (SMEs).

Knowledge sharing culture and process innovation. A strong knowledge-sharing culture in digital printing SMEs fosters process innovation. By sharing information and experiences, employees can develop more efficient and creative work methods, improving product and service quality. Research by (Nonaka et al., 2002) emphasizes the importance of knowledge sharing in driving organizational innovation. Additionally, a study by (Wuryaningrum et al., 2020) showed that knowledge management has a positive and significant impact on product innovation in SMEs in Indonesia.

Knowledge sharing culture and supply chain sustainability. The knowledge-sharing culture also contributes positively to supply chain sustainability. Effective collaboration and information exchange between employees and business partners ensure the smooth flow of goods and information, reducing risks of disruptions and improving responsiveness to market demand changes. Research by (C. Y. Lin et al., 2024) underscores that knowledge-sharing capabilities support organizational competitive advantage. In Indonesia, a study by (I. Ahmad et al., 2023) indicated that knowledge sharing significantly influences innovation capabilities in the supply chain.

Information technology and the challenges in its implementation. The finding that information technology has a significant negative impact on process innovation and supply chain sustainability highlights the challenges in its implementation. This aligns with research by (Ramdani et al., 2013), which notes that technology adoption can face barriers due to organizational readiness. A study by (Istanto et al., 2022) in Indonesia also identified that the adoption of technology in SMEs is often influenced by human and financial resource constraints.

Process innovation and supply chain sustainability. Although process innovation contributes positively to supply chain sustainability, its impact is relatively small. Research by (Cousins et al., 2019) shows that supply chain sustainability is determined not only by process innovation but also by relationships with business partners and environmental strategies. In the Indonesian context, a study by (Hidayati et al., 2023) highlighted that supply chain digitalization affects operational sustainability and SME performance. Therefore, SMEs need to foster a knowledge-sharing culture, enhance information technology skills, integrate technology with business processes, and adopt a holistic approach to managing supplier and customer relationships. With this strategy, digital printing SMEs can overcome challenges and improve their competitiveness in the global supply chain.

5.2. Indirect Effects (Mediating)

Knowledge sharing culture plays a crucial role in enhancing supply chain sustainability through process innovation. By sharing ideas, experiences, and best practices, digital printing SMEs in Indonesia can develop more efficient and environmentally friendly process innovations. Research by (Arsawan et al., 2022) shows that knowledge sharing significantly improves the innovation culture, which ultimately strengthens sustainable competitive advantage. Additionally, a study by (Barcia et al., 2022) emphasizes the importance of process innovation in mediating the relationship between lean practices and supply chain sustainability. This reinforces the finding that process innovation is a key pathway in linking knowledge sharing culture to supply chain sustainability.

However, the negative mediation effect of information technology on supply chain sustainability indicates challenges in its implementation. Poorly managed technology can lead to inefficiencies, such as employee resistance or the organization's inability to fully capitalize on the benefits of technology. Research by (Istanto et al., 2022) in Indonesia identified that a lack of training and management support often serves as a barrier to technology adoption by SMEs. Moreover, a study by (Anwar & Abadi, 2023) emphasizes the importance of transformational leadership in effectively leveraging technology to improve organizational performance.

Therefore, digital printing SMEs in Indonesia need to prioritize strengthening their knowledge sharing culture, enhancing process innovation capabilities, and improving information technology management. Investment in employee training and organizational readiness analysis before adopting new technology is crucial to ensure maximum benefits. With this approach, supply chain sustainability can be achieved, even in the face of market uncertainty.

5.3. Effects Moderating

Market uncertainty has a significant positive influence on supply chain sustainability in digital printing SMEs in Indonesia, indicating that uncertain market conditions drive companies to focus more on sustainability strategies to face challenges. However, market uncertainty also weakens the relationship between process innovation and supply chain sustainability, suggesting that in unstable situations, the effectiveness of process innovation may decrease. Research by (Kaewsaeng-on, 2023). underscores the importance of knowledge sharing in driving sustainable innovation, while a study by (Roscoe et al., 2016). shows that process innovation and supply chain management have a positive impact on SME performance. In the context of uncertainty, (Istanto et al., 2022) found that resistance to technology and resource limitations often hinder the implementation of sustainability strategies.

To address these challenges, SMEs need to enhance their flexibility and adaptability to market changes, strengthen risk management to anticipate uncertainty, and integrate technology with the right strategies. Additionally, encouraging collaboration and knowledge sharing among employees and business partners can help improve innovation and supply chain resilience. With these measures, SMEs can remain competitive and sustainable, even when facing market uncertainty.

6. Research implications

6.1. Theoretical Implications

The findings contribute significantly to the literature on supply chain sustainability, process innovation, and the role of organizational factors such as knowledge sharing culture and information technology. Specifically, the theoretical implications of these findings can be outlined as follows:

Strategic role of knowledge sharing culture. The finding that knowledge sharing culture has the greatest positive influence on process innovation and supply chain sustainability supports the dynamic knowledge theory of (C. Y. Lin et al., 2024). Knowledge is considered a core asset in creating innovative value. This study extends the understanding by confirming that knowledge sharing is not only relevant for innovation but also plays a critical role in supply chain sustainability. It suggests that organizations promoting internal and external collaboration have a greater chance of improving sustainability performance.

Contribution and limitations of process innovation. The finding that process innovation contributes positively to supply chain sustainability, albeit with a small effect, supports the organizational innovation theory, which states that operational innovation is crucial for efficiency and sustainability. However, this small impact indicates that process innovation may not be the only path to sustainability, reinforcing the argument by (Cousins et al., 2008) that other factors, such as business partner relationships and environmental strategies, must also be considered in future research.

The paradox of information technology. The negative impact of information technology on process innovation and supply chain sustainability indicates implementation challenges. This finding supports the technology contingency theory, which emphasizes that technology must align with organizational needs to be effective. Identified barriers such as organizational readiness and resource limitations (Akter et al., 2024) highlight the importance of context-specific technology adaptation.

Market uncertainty moderating effect. The significant positive impact of market uncertainty on supply chain sustainability suggests that dynamic market conditions can drive organizations to adopt more proactive sustainability strategies. However, the negative moderating effect on the relationship between process innovation and supply chain sustainability indicates that market uncertainty can reduce the effectiveness of process innovation. This provides new insights into market dynamics theory, showing that market uncertainty can be a double-edged sword for organizational performance.

Mediation in sustainability pathways. The mediating effect of knowledge sharing culture through process innovation on supply chain sustainability emphasizes that process innovation is a crucial pathway for enhancing sustainability. This finding enriches the open innovation theory by showing how internal knowledge sharing can drive sustainability outcomes through process innovation.

Overall, this study highlights the importance of integrating organizational factors, innovation, and technology in managing sustainable supply chains. Future research could further explore the influence of contextual factors such as national culture, industry, or policies on these relationships to broaden insights in various contexts.

6.2. Managerial Implications

The findings of this study provide practical guidance for managers of digital printing SMEs to enhance their supply chain sustainability, especially in the face of market uncertainty. To promote the success of a knowledge sharing culture, managers need to create an open work environment that supports collaboration among employees by providing technology-based platforms for information exchange and offering incentives for employees who actively share knowledge.

Additionally, although process innovation has a relatively small impact on supply chain sustainability, managers should still prioritize identifying and implementing innovations in inefficient processes, while ensuring employee involvement in every stage. Information technology management also requires extra attention, focusing on evaluating organizational readiness before adopting new technologies and providing employee training to enhance relevant technological skills.

In the face of market uncertainty, managers should develop proactive risk management systems and strengthen operational flexibility to better respond to changes in demand or supply disruptions. Finally, mediation strategies that integrate knowledge sharing culture and process innovation should be effectively implemented to strengthen the relationships between the factors contributing to supply chain sustainability.

With this approach, digital printing SMEs can improve their competitiveness and achieve better sustainability while facing the challenges of a dynamic market.

7. Conclusions, Limitations and Future Research

This study provides valuable insights into the role of knowledge sharing culture, information technology support, and process innovation in enhancing supply chain sustainability in the digital printing SME sector in Indonesia. The analysis results show that all relationships in the research model are statistically significant, with knowledge sharing culture having the largest positive impact on process innovation and supply chain sustainability. Process innovation also proves to have a positive impact on supply chain sustainability, although with a relatively small effect. In contrast, information technology support shows a negative impact on process innovation and supply chain sustainability, highlighting the challenges in its implementation. Market uncertainty acts as a moderating variable that strengthens supply chain sustainability but weakens the relationship between process innovation and sustainability. The mediation effects found indicate that process innovation plays a key role in linking knowledge sharing culture with supply chain sustainability, while information technology requires more careful management to mitigate its negative effects.

This study has several limitations that should be considered. First, the approach used is cross-sectional, which only allows for the analysis of relationships between variables at a single point in time and cannot capture long-term changes in the dynamics under investigation. Second, the sample used is limited to digital printing SMEs in Indonesia, so the results may not be fully generalizable to other SME sectors or different countries. Third, while this study uses the PLS-SEM model to test complex relationships, the model only includes selected variables and does not account for other factors that may affect supply chain sustainability, such as social or environmental factors.

Future research can address these limitations by using a longitudinal approach to explore the changes in relationships between variables over time, especially in the context of evolving market dynamics. Studies in other SME sectors, both in Indonesia and other countries, should also be conducted to test whether these findings are more broadly applicable or if there are significant sectoral differences. Furthermore, future research can expand the model by incorporating other factors that influence supply chain sustainability, such as social impact, government policies, or environmental factors. Given the challenges faced by SMEs in adopting technology, further studies on the effective management of information technology in the SME context will provide deeper insights into the influence of technology on supply chain sustainability.

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