The Impact of Supply Chain Management Practices, Information Technology Capabilities, and Supply Chain Capabilities on Supply Chain Operational Performance: Mediating Role of Supply Chain Technology Adoption in Beijing's Cold Storage Industry

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Abstract
The rapid digital transformation of supply chains has intensified the need to understand how organizational and technological factors influence operational performance, particularly within specialized sectors such as the cold storage industry. Despite growing investments in digital infrastructure, inconsistencies remain regarding the role of technology adoption and organizational capabilities in enhancing performance, revealing a critical research gap in emerging economies such as China. This study examines the impact of supply chain management practices (SCMP), information technology capabilities (ITC), and supply chain capabilities (SCC) on supply chain operational performance (SCOP), with supply chain technology adoption (SCTA) as a mediating variable, grounded in the Technology-Organization-Environment (TOE) framework. A quantitative approach was employed using survey data collected from 350 respondents, with 300 valid responses from supply chain personnel and managers in Beijing's cold storage firms, analysed using SmartPLS. The findings indicate that SCMP significantly influences SCTA (H1: $\beta = -0.488$, $t = 6.631$, $p < 0.001$) and SCOP (H4: $\beta = -0.178$, $t = 2.661$, $p = 0.008$), while SCC demonstrates a strong positive effect on SCOP (H6: $\beta = 0.739$, $t = 18.980$, $p < 0.001$). SCTA significantly affects SCOP (H7: $\beta = -0.387$, $t = 6.731$, $p < 0.001$) and partially mediates the relationship between SCMP and SCOP (H8: $\beta = 0.189$, $t = 4.344$, $p < 0.001$), indicating competitive partial mediation. In contrast, ITC shows no significant direct or indirect effects (H2, H5, H9). These results highlight the dominant role of organizational capabilities over technological readiness and underscore the importance of effective technology implementation. The study contributes theoretically by extending the TOE framework in a cold storage context and offers practical insights for enhancing supply chain performance through capability development and strategic technology adoption.

Keywords
Supply Chain Management Practices, Information Technology Capabilities, Supply Chain Capabilities, Supply Chain Technology Adoption, Supply Chain Operational Performance, Technology-Organization-Environment (TOE) Framework, Cold Storage Industry, PLS-SEM

1.0 Introduction

The rapid transformation of global supply chains, driven by digitalization and increasing demand for perishable goods, has positioned the cold storage industry as a critical component of national economic and food security systems. In China, the cold chain logistics sector has experienced substantial growth due to rising urbanization, expanding e-commerce, and increasing consumption of temperature-sensitive products such as fresh food and pharmaceuticals (Shi et al., 2024). As a major logistics hub, Beijing plays a pivotal role in facilitating efficient distribution networks and ensuring product quality across supply chains. Within this context, enhancing supply chain operational performance (SCOP) has become a strategic priority for firms operating in the cold storage industry. The integration of supply chain management practices (SCMP), information technology capabilities (ITC), and supply chain capabilities (SCC) is increasingly recognized as essential for achieving operational excellence. However, the effectiveness of these capabilities largely depends on the extent to which firms adopt advanced supply chain technologies. Therefore, understanding the mechanisms through which organizational and technological factors influence performance is of significant importance for both academia and industry.

Despite the growing emphasis on supply chain efficiency, several systemic challenges persist within China's logistics and cold storage sectors. One of the primary issues is the fragmentation of supply chain networks, which limits effective coordination and information sharing among stakeholders (Ahmed et al., 2024). Additionally, disparities in technological readiness across firms hinder the widespread adoption of advanced supply chain technologies, resulting in inefficiencies in inventory management, transportation, and monitoring systems (Hinneh & Sangal, 2025). Organizational constraints, such as weak supply chain capabilities, limited trust among partners, and inadequate strategic alignment, further exacerbate these challenges (Tao et al., 2025). These issues are particularly pronounced in the cold storage industry, where operational precision and real-time coordination are critical for maintaining product integrity. Consequently, firms face increasing pressure to enhance their capabilities and adopt digital solutions to remain competitive in a rapidly evolving market environment.

In the cold storage industry, the complexity of operations introduces additional challenges that directly impact supply chain performance. Maintaining consistent temperature control, ensuring timely delivery, and minimizing product spoilage require advanced technological systems and highly coordinated processes. However, many firms continue to rely on traditional supply chain practices and exhibit limited integration of digital technologies such as Internet of Things (IoT), RFID, and automation systems (Sallam et al., 2023). This lack of technological adoption creates inefficiencies in monitoring and decision-making, ultimately affecting supply chain operational performance. Furthermore, even when technological solutions are available, their adoption is often constrained by insufficient organizational capabilities and inadequate information technology infrastructure. This disconnect between available technologies and actual implementation highlights a critical need to examine how supply chain management practices, technological capabilities, and organizational capabilities jointly influence technology adoption and performance outcomes within the industry.

Although prior studies have explored the relationships between supply chain practices, technological capabilities, and performance, significant research gaps remain. Existing research has predominantly focused on manufacturing and general logistics sectors, with limited attention given to the cold storage industry, particularly within the Chinese context (Mustafa et al., 2024). Moreover, few studies have comprehensively examined the mediating role of supply chain technology adoption (SCTA) in linking SCMP, ITC, and SCC to SCOP. This study addresses these gaps by investigating the impact of supply chain management practices, information technology capabilities, and supply chain capabilities on supply chain operational performance, with supply chain technology adoption as a mediating variable among cold storage firms in Beijing, China. The selection of Beijing is particularly significant due to its strategic role in China's logistics network and its advanced infrastructure, which provides a suitable context for examining supply chain transformation. Additionally, focusing on supply chain personnel and managers addresses the population gap by capturing insights from key decision-makers responsible for technology adoption and operational performance, thereby enhancing the relevance and applicability of the findings.

This study offers several novel contributions. Theoretically, it adopts the Technology-Organization-Environment (TOE) framework as a unified lens to explain the interplay between organizational capabilities, technological readiness, and environmental context in influencing technology adoption and performance outcomes. Methodologically, the study employs a quantitative approach using Partial Least Squares Structural Equation Modeling (PLS-SEM), enabling the examination of complex relationships and mediation effects within the proposed framework. Practically, the findings provide actionable insights for industry practitioners and policymakers aiming to enhance supply chain efficiency through strategic capability development and technology adoption. The remainder of this paper is structured as follows: the next section reviews the relevant literature and theoretical framework, followed by hypothesis development. The methodology section outlines the research design and data analysis procedures, after which the results and discussion are presented. Finally, the paper concludes with implications, limitations, and recommendations for future research.

1.1 Problem Statement

Despite the increasing importance of supply chain management in enhancing operational performance, existing literature reveals persistent gaps in understanding how organizational and technological factors interact to influence performance outcomes, particularly in specialized industries such as cold storage. Previous studies have established that supply chain management practices and technological capabilities contribute to improved performance; however, the findings are often inconsistent across different contexts and industries (Garcia-Buendia et al., 2022). One major limitation is that many studies focus primarily on direct relationships, neglecting the role of technology adoption as a mediating mechanism that translates capabilities into operational performance. As highlighted by Rahimi & Oh (2025), the absence of a comprehensive framework integrating organizational, technological, and adoption factors limits the explanatory power of existing models.

Furthermore, research on supply chain technology adoption remains fragmented, with limited empirical evidence on how adoption processes influence operational performance in the cold storage sector. It was emphasized by Kumar Singh et al. (2024) that while technologies such as IoT and RFID have the potential to enhance efficiency, their adoption is uneven and often constrained by organizational and infrastructural limitations. This indicates a significant gap in understanding the determinants and outcomes of technology adoption within this industry. Additionally, most existing studies are conducted in developed economies or focus on large-scale logistics operations, leaving a geographical and contextual gap in emerging markets such as China, particularly in Beijing's cold storage industry (Sun et al., 2023).

Another critical issue lies in the lack of integration between different capability dimensions. While supply chain management practices, information technology capabilities, and supply chain capabilities have been studied independently, there is limited research examining their combined effects on technology adoption and operational performance. This fragmented approach fails to capture the complexity of real-world supply chains, where multiple factors interact simultaneously to influence outcomes. Moreover, the perspectives of supply chain personnel and managers, who play a crucial role in implementing practices and technologies, are often overlooked, creating a population gap in the literature.

In response to these gaps, this study proposes a comprehensive framework that integrates SCMP, ITC, and SCC as key determinants of supply chain technology adoption and operational performance. By adopting the TOE framework, the study provides a holistic explanation of how technological, organizational, and contextual factors influence performance outcomes. The use of PLS-SEM further enables the examination of both direct and indirect relationships, offering a more nuanced understanding of the mechanisms underlying supply chain performance. By focusing on cold storage firms in Beijing, this study addresses both geographical and industry-specific gaps, contributing to the development of contextually relevant and empirically grounded insights. Ultimately, the findings of this study are expected to provide valuable guidance for improving supply chain efficiency and supporting the sustainable development of the cold storage industry.

2.0 Literature Review

The present study is grounded in the Technology-Organization-Environment framework, which provides a comprehensive theoretical lens to explain how technological adoption within organizations is shaped by technological readiness, organizational capabilities, and environmental conditions. The TOE framework is particularly relevant in the context of China's cold storage industry, where rapid digital transformation is being driven by both market forces and government policies. In recent years, the Chinese government has actively promoted the modernization of cold chain logistics through strategic initiatives emphasizing smart logistics, digital infrastructure, and food safety regulation, thereby creating an enabling environment for technology adoption (Han et al., 2026). Within this policy-driven context, cold storage firms in Beijing, one of China's most advanced logistics hubs, are under increasing pressure to integrate technological solutions into their operations. The TOE framework aligns closely with this study's targeted population, namely supply chain personnel and managers, as these actors are directly responsible for implementing supply chain management practices, developing organizational capabilities, and facilitating technology adoption decisions. Consequently, the framework provides a robust theoretical foundation to explain how organizational factors such as supply chain management practices (SCMP) and supply chain capabilities (SCC), together with technological factors such as information technology capabilities (ITC), influence supply chain technology adoption (SCTA) and ultimately enhance supply chain operational performance (SCOP) in the cold storage sector.

Supply chain operational performance (SCOP), the central outcome variable of this study, is widely recognized as a multidimensional construct encompassing reliability, responsiveness, agility, and cost efficiency, all of which are critical in temperature-sensitive logistics environments. In the cold storage industry, high levels of SCOP are essential to minimize product spoilage, ensure timely delivery, and maintain quality standards, thereby directly influencing firm competitiveness (Lei, 2025). Contemporary literature suggests that SCOP is significantly influenced by both organizational practices and technological capabilities. Supply chain management practices (SCMP), particularly those related to information sharing, coordination, and integration, have been shown to enhance operational efficiency by reducing uncertainties and improving collaboration among supply chain partners (Obiri-Yeboah et al., 2025). Similarly, information technology capabilities (ITC) enable firms to leverage digital tools for real-time data processing, monitoring, and decision-making, which are critical for optimizing cold storage operations (Buzuleeva, 2025). Supply chain capabilities (SCC), including organizational culture, trust, and strategic sourcing, further strengthen performance by fostering adaptability and resilience within supply networks (Polater, 2025). However, recent studies highlight that these relationships are not purely direct; instead, their effectiveness is often contingent upon the extent to which firms adopt advanced supply chain technologies (Zelbst et al., 2023).

From a critical perspective, prior research has largely examined SCMP, ITC, and SCC in isolation, with limited integration of these variables within a unified framework. This fragmented approach fails to capture the complex interactions among organizational and technological factors in real-world supply chains. For instance, ITC has been found to enhance the effectiveness of SCMP by enabling better information sharing and coordination, while SCC strengthens the implementation of both SCMP and ITC through improved organizational alignment and trust (Jinjiri et al., 2023). These interdependencies suggest that the combined influence of these variables is more significant than their individual effects. Furthermore, supply chain technology adoption (SCTA), which includes technologies such as IoT, RFID, and automation systems, plays a critical mediating role by transforming organizational and technological capabilities into tangible performance outcomes (Mashat et al., 2024). Despite this, empirical evidence on the mediating role of SCTA remains limited, particularly in the cold storage sector and within emerging economies such as China. This highlights the need for a comprehensive model that integrates SCMP, ITC, SCC, and SCTA to explain SCOP more effectively.

Building on the TOE framework and existing empirical findings, this study posits that supply chain management practices, information technology capabilities, and supply chain capabilities exert both direct and indirect effects on supply chain operational performance through supply chain technology adoption. Specifically, it is hypothesized that SCMP, ITC, and SCC are significantly related to SCTA (H1–H3), reflecting the influence of organizational and technological contexts on adoption decisions. Additionally, SCMP, ITC, and SCC are expected to have significant relationships with SCOP (H4–H6), consistent with prior research emphasizing the role of capabilities in enhancing operational performance. Supply chain technology adoption is further hypothesized to be significantly related to SCOP (H7), highlighting its role as a critical enabler of efficiency and effectiveness in cold storage operations. Finally, SCTA is proposed to mediate the relationships between SCMP and SCOP (H8), ITC and SCOP (H9), and SCC and SCOP (H10), thereby providing a comprehensive explanation of how organizational and technological factors are translated into performance outcomes. These hypotheses collectively address the limitations of previous studies by integrating multiple capability dimensions and emphasizing the mediating role of technology adoption within the specific context of Beijing's cold storage industry.

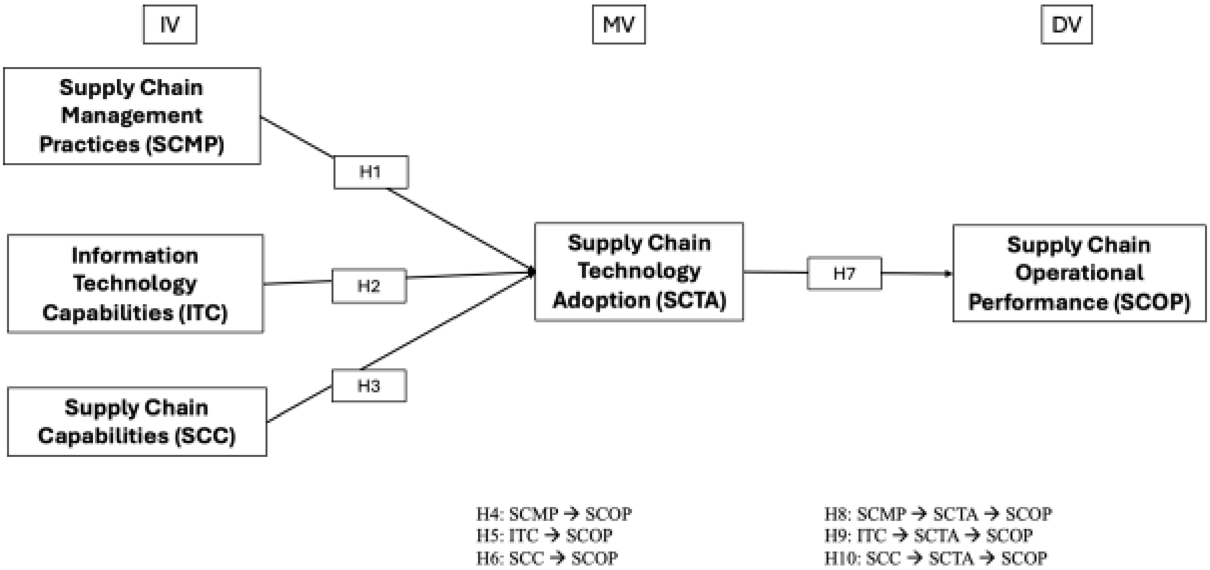

Figure 1: Conceptual Framework of the Relationships among Supply Chain Management Practices, Information Technology Capabilities, Supply Chain Capabilities, Supply Chain Technology Adoption, and Supply Chain Operational Performance

Figure 1 presents the conceptual framework of the study, illustrating the hypothesized relationships among supply chain management practices (SCMP), information technology capabilities (ITC), and supply chain capabilities (SCC) as the independent variables, supply chain technology adoption (SCTA) as the mediating variable, and supply chain operational performance (SCOP) as the dependent variable. The framework proposes that SCMP, ITC, and SCC exert both direct effects on SCOP and indirect effects through SCTA, reflecting a mediation mechanism grounded in the Technology-Organization-Environment (TOE) framework. The hypothesized paths (H1–H7) depict the direct relationships among variables, while the mediating structure highlights the role of technology adoption in translating organizational and technological capabilities into performance outcomes. This framework provides a comprehensive model for examining how internal capabilities and technology adoption jointly influence operational efficiency within Beijing's cold storage industry.

3.0 Methodology

3.1 Research Design

This study adopts a quantitative research design grounded in a positivist paradigm to examine the relationships among supply chain management practices (SCMP), information technology capabilities (ITC), supply chain capabilities (SCC), supply chain technology adoption (SCTA), and supply chain operational performance (SCOP) within the cold storage industry in Beijing, China. A deductive approach is employed to test the proposed hypotheses derived from the Technology-Organization-Environment (TOE) framework. The use of a structured survey enables the collection of standardized data suitable for statistical analysis, while Partial Least Squares Structural Equation Modeling (PLS-SEM) is applied to assess both direct and mediating relationships. PLS-SEM is particularly appropriate for this study due to its ability to handle complex models, latent constructs, and non-normal data distributions, as well as its suitability for predictive research models (Hair et al., 2021).

3.2 Population and Sampling

The target population comprises supply chain personnel and managers working in cold storage firms in Beijing, China, as they possess the relevant knowledge and experience regarding supply chain practices and technology adoption. A purposive sampling technique is adopted to ensure that respondents are selected based on their involvement in supply chain operations and decision-making processes. This approach is appropriate given the specialized nature of the study and the need for informed respondents. A total of 438 questionnaires were distributed, of which 350 were returned, yielding a response rate of 80%. From these, 300 valid responses were retained for analysis after data screening. The sample size is considered adequate for PLS-SEM analysis and aligns with recommended thresholds for ensuring statistical power and model stability (Sarstedt et al., 2022).

3.3 Data Collection Procedure

Data were collected using a self-administered questionnaire distributed to respondents across cold storage firms in Beijing. The survey was conducted over a specified period to ensure sufficient participation and data completeness. Respondents were informed about the purpose of the study and assured of the confidentiality and anonymity of their responses. Participation was voluntary, and informed consent was obtained prior to data collection. To minimize common method bias, procedural remedies such as clear instructions, assured anonymity, and the use of different scale anchors were implemented.

3.4 Measurement Instrument

The measurement instrument was developed based on validated scales from prior studies, ensuring content validity and reliability. All constructs were measured using a five-point Likert scale ranging from strongly disagree to strongly agree. Supply chain operational performance (SCOP) was measured using items adapted from Ngo et al. (2024) and Beamon's performance dimensions, capturing aspects such as reliability (e.g., ability to meet delivery requirements), responsiveness (e.g., speed of order fulfillment), agility (e.g., ability to respond to demand changes), and cost efficiency (e.g., operational cost reduction). Supply chain management practices (SCMP) were measured using items adapted from Hani (2022), including information sharing (e.g., extent of information exchange with partners), coordination (e.g., alignment of activities across the supply chain), and integration (e.g., collaboration with suppliers and customers). Information technology capabilities (ITC) were assessed using items adapted from Alkatheeri et al. (2023) focusing on technological infrastructure (e.g., availability of digital systems), IT personnel (e.g., expertise of IT staff), and system integration (e.g., ability to integrate information across platforms). Supply chain capabilities (SCC) were measured using items adapted from Luqman et al., (2023), including organizational culture (e.g., adaptability and innovation), trust (e.g., trust among supply chain partners), and strategic sourcing (e.g., long-term supplier relationships). Finally, supply chain technology adoption (SCTA) was measured using items adapted from Lyu et al. (2024) capturing the extent of adoption and utilization of technologies such as IoT, RFID, and automation systems in supply chain operations. These items collectively reflect the constructs under investigation and ensure alignment with the theoretical framework.

3.5 Data Analysis Technique

Data analysis was conducted using PLS-SEM to evaluate both the measurement model and the structural model. The measurement model was assessed in terms of reliability, convergent validity, and discriminant validity, while the structural model was evaluated based on path coefficients, coefficient of determination (R^2), effect size (f^2), and predictive relevance (Q^2). Bootstrapping procedures were employed to test the significance of the hypothesized relationships, including the mediating effects of supply chain technology adoption. This approach enables a comprehensive assessment of the proposed model and provides robust empirical evidence for hypothesis testing.

3.6 Ethical Considerations

Ethical considerations were strictly adhered to throughout the research process. Respondents were fully informed about the purpose of the study and their right to withdraw at any time without penalty. Confidentiality and anonymity were ensured by not collecting personally identifiable information and by reporting data in aggregate form. The study complied with institutional ethical guidelines and ensured that data were used solely for academic purposes. These measures were implemented to uphold research integrity and protect the rights of participants.

4.0 Results and Discussion

4.1 Overview of Data and Respondents

A total of 438 questionnaires were distributed to supply chain personnel and managers in cold storage firms in Beijing, China, of which 350 were returned, representing a high response rate of 80%. After data screening for completeness and consistency, 300 valid responses were retained for analysis, which is considered adequate for Partial Least Squares Structural Equation Modeling (PLS-SEM) and satisfies recommended sample size requirements for robust statistical inference (Hair et al., 2021). The high response rate and sufficient sample size indicate strong respondent engagement and enhance the reliability of the dataset for subsequent analysis. The respondents, comprising individuals directly involved in supply chain operations and decision-making, provide relevant and contextually valid insights into the constructs under investigation, thereby supporting the generalizability of the findings within the Beijing cold storage industry context .

Table 1: Demographic Characteristics of Respondents in Beijing's Cold Storage Industry

Demographic Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	214	61.1
	Female	136	38.9
Age	Below 25 years	42	12.0
	26–35 years	146	41.7
	36–45 years	108	30.9
	Above 45 years	54	15.4
Educational Level	Diploma	60	17.1
	Bachelor's Degree	196	56.0
	Master's Degree	80	22.9
	Doctorate	14	4.0
Job Position	Supply Chain Manager	112	32.0
	Logistics/Operations Manager	86	24.6
	Supervisor	78	22.3
	Executive/Staff	74	21.1
Work Experience	Less than 3 years	52	14.9
	3–5 years	114	32.6
	6–10 years	122	34.9
	More than 10 years	62	17.7
Firm Size	Small (<50 employees)	72	20.6
	Medium (50–249 employees)	166	47.4
	Large (≥250 employees)	112	32.0

Table 1 presents the demographic characteristics of the respondents, providing an overview of the sample composition within Beijing's cold storage industry. The findings indicate that the majority of respondents are male (61.1%) and fall within the 26–35 years age group (41.7%), reflecting a relatively young and active workforce in supply chain operations. Most respondents possess a bachelor's degree (56.0%), followed by master's degree holders (22.9%), suggesting a well-educated sample capable of providing informed insights. In terms of professional roles, supply chain managers (32.0%) and logistics or operations managers (24.6%) constitute the largest groups, ensuring that the data are derived from individuals with substantial decision-making authority. The distribution of work experience shows that a significant proportion of respondents have between 6 to 10 years of experience (34.9%), indicating a high level of expertise. Additionally, the majority of respondents are employed in medium-sized firms (47.4%), followed by large firms (32.0%), which reflects the structural composition of the cold storage sector in Beijing. Overall, the demographic profile supports the representativeness and reliability of the sample for examining supply chain performance and technology adoption.

4.2 Measurement Model Assessment

The measurement model was evaluated to ensure reliability and validity of the constructs prior to structural model analysis. Factor loadings for all indicators (as provided in the supplementary data) exceeded the recommended threshold of 0.70, with values ranging from 0.889 to 0.973, indicating strong indicator reliability (Hair et al., 2021). These high loadings demonstrate that the observed variables adequately represent their respective latent constructs, namely SCMP, ITC, SCC, SCTA, and SCOP.

Internal consistency reliability was assessed using Cronbach's alpha and composite reliability (rho_a and rho_c). All constructs exhibited Cronbach's alpha values ranging from 0.962 to 0.981 and composite reliability values exceeding 0.97, which are well above the recommended threshold of 0.70, confirming excellent reliability (Table 2). Convergent validity was evaluated using the Average Variance Extracted (AVE), with all constructs reporting AVE values between 0.842 and 0.914, exceeding the minimum requirement of 0.50. These results indicate that the constructs explain a substantial proportion of variance in their respective indicators, thereby confirming convergent validity (Sarstedt et al., 2022).

Table 2: Construct reliability and validity value.

Variables	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
ITC	0.962	0.963	0.970	0.842
SCC	0.981	0.982	0.985	0.914
SCMP	0.976	0.977	0.981	0.894
SCOP	0.971	0.971	0.976	0.872
SCTA	0.974	0.974	0.979	0.884

4.2.1 Discriminant Validity

Discriminant validity was assessed using the Heterotrait-Monotrait ratio (HTMT). All HTMT values which reported in table 3, ranged between 0.185 and 0.708, which are below the conservative threshold of 0.85, indicating that the constructs are empirically distinct from one another. This confirms that each construct captures a unique aspect of supply chain management and technology adoption within the model. The establishment of discriminant validity ensures that multicollinearity issues are minimized and that the constructs can be reliably used for further structural analysis (Henseler et al., 2021).

Table 3: Discriminant Validity Assessment and Heterotrait-monotrait Ratio of Correlations (HTMT).

Variables	ITC	SCC	SCMP	SCOP	SCTA
ITC					
SCC	0.502				
SCMP	0.696	0.362			
SCOP	0.294	0.708	0.222		
SCTA	0.416	0.185	0.550	0.390	

4.2.2 Model Fit Assessment

Model fit was evaluated using standardized root mean square residual (SRMR) and normed fit index (NFI). The SRMR value of 0.028 which reported in Table 4, is well below the recommended threshold of 0.08, indicating a good model fit. Similarly, the NFI value of 0.920 exceeds the acceptable benchmark of 0.90, further confirming that the proposed model adequately represents the observed data. These indices collectively suggest that the measurement model demonstrates satisfactory goodness-of-fit and is suitable for further analysis using PLS-SEM (Hair et al., 2021).

Table 4: Model Fit

SRMR	**0.028**
NFI	0.920

4.2.3 Coefficient of Determination (R^2)

The explanatory power of the model was assessed using the coefficient of determination (R^2). The results indicate that supply chain operational performance (SCOP) has an R^2 value of 0.939, suggesting that approximately 93.9% of the variance in SCOP is explained by SCMP, ITC, SCC, and SCTA. Similarly, supply chain technology adoption (SCTA) has an R^2 value of 0.893, indicating that 89.3% of its variance is explained by SCMP, ITC, and SCC (Table 5). These values are considered substantial, demonstrating strong predictive capability of the model and indicating that the selected independent variables effectively explain both the mediator and the dependent variable (Hair et al., 2021).

Table 5: R-square adjusted value

Variables	**R-square**	**R-square adjusted**
SCOP	0.939	0.937
SCTA	0.893	0.891

4.2.4 Effect Size (f^2)

The effect size (f^2) was examined to evaluate the relative impact of each exogenous construct on endogenous variables. The results in table 6 showed that SCC has a very large effect on SCOP (f^2 = 1.007), indicating that supply chain capabilities play a dominant role in determining operational performance. SCTA also demonstrates a moderate effect on SCOP (f^2 = 0.257), highlighting the importance of technology adoption as a driver of performance. SCMP exhibits a small to moderate effect on both SCOP (f^2 = 0.035) and SCTA (f^2 = 0.183), suggesting its supportive role in enhancing both adoption and performance. In contrast, ITC shows relatively small effects on both SCOP (f^2 = 0.014) and SCTA (f^2 = 0.006), indicating that while technological capabilities are important, their influence may be mediated through other constructs such as SCTA and SCC. These findings provide nuanced insights into the relative importance of each variable within the model (Hair et al., 2021).

Table 6: F-square value

Items	**f-square**
ITC -> SCOP	0.014
ITC -> SCTA	0.006
SCC -> SCOP	1.007
SCC -> SCTA	0.001
SCMP -> SCOP	0.035
SCMP -> SCTA	0.183
SCTA -> SCOP	0.257

4.3 Structural Model Results and Hypotheses Testing

The structural model was evaluated using the bootstrapping procedure to assess the significance and strength of the hypothesized relationships among supply chain management practices (SCMP), information technology capabilities (ITC), supply chain capabilities (SCC), supply chain technology adoption (SCTA), and supply chain operational performance (SCOP). The results reported in Table 7 demonstrate varying levels of significance across the proposed relationships, offering important theoretical and empirical insights within the context of the Technology-Organization-Environment (TOE) framework.

The relationship between supply chain management practices and supply chain technology adoption is found to be statistically significant, with a path coefficient of $\beta = -0.488$, $t = 6.631$, and $p < 0.001$, thus supporting H1. Despite the negative direction, the significance indicates that SCMP plays a crucial role in influencing technology adoption decisions within Beijing's cold storage firms. This finding suggests that certain existing supply chain practices may be misaligned with or resistant to technological transformation, thereby negatively affecting adoption levels. Similar counterintuitive findings have been reported in recent studies, where traditional operational routines hinder digital transformation due to structural inertia or lack of adaptability (Kaganer et al., 2023). From the TOE perspective, this reflects the complexity of organizational context, where not all established practices facilitate innovation adoption.

In contrast, the relationship between information technology capabilities and supply chain technology adoption is not statistically significant ($\beta = -0.092$, $t = 1.063$, $p = 0.288$), leading to the rejection of H2. Similarly, supply chain capabilities do not significantly influence technology adoption ($\beta = 0.036$, $t = 0.725$, $p = 0.468$), resulting in the rejection of H3. These findings suggest that, within the Beijing cold storage industry, neither technological readiness nor organizational capabilities alone are sufficient to drive the adoption of advanced supply chain technologies. This contradicts some prior studies that emphasize IT capability as a key driver of adoption (Lee et al., 2024), but aligns with emerging evidence indicating that external pressures, institutional support, or strategic intent may play a more decisive role in technology adoption decisions (Zhang et al., 2025). Thus, the TOE framework remains valid but indicates that the technological and organizational dimensions may not be fully leveraged in this specific context.

Regarding the direct effects on supply chain operational performance, supply chain management practices exhibit a statistically significant relationship with SCOP ($\beta = -0.178$, $t = 2.661$, $p = 0.008$), supporting H4. However, the negative coefficient suggests that current practices may not be optimized for performance enhancement, potentially due to inefficiencies or lack of integration in cold storage operations. This finding is consistent with recent literature indicating that poorly coordinated or outdated practices can hinder operational efficiency despite their intended purpose (Mohammed, 2024).

Information technology capabilities do not show a statistically significant effect on SCOP ($\beta = -0.111$, $t = 1.710$, $p = 0.087$), leading to the rejection of H5. This implies that IT infrastructure alone does not directly translate into improved operational performance, reinforcing the argument that technology must be effectively integrated and utilized to generate value. Prior research supports this view, highlighting that IT investments require complementary organizational capabilities to produce performance gains (Mikalef et al., 2023)

In contrast, supply chain capabilities demonstrate a highly significant and strong positive effect on SCOP ($\beta = 0.739$, $t = 18.980$, $p < 0.001$), providing strong support for H6. This result underscores the critical importance of organizational and relational capabilities, such as trust, strategic sourcing, and adaptive culture, in driving operational performance in the cold storage sector. The magnitude of this relationship confirms that SCC is the most influential determinant of SCOP in this study, aligning with recent findings that emphasize the role of dynamic capabilities in enhancing supply chain efficiency and resilience (Mohsin et al., 2025).

The relationship between supply chain technology adoption and supply chain operational performance is also statistically significant (β = -0.387, t = 6.731, $p < 0.001$), supporting H7. However, the negative direction suggests that technology adoption, in its current form, may not be effectively implemented or fully utilized within the industry. This may reflect challenges such as inadequate training, lack of integration, or high implementation costs, which can offset the expected benefits of technology adoption. Recent studies have similarly reported that the impact of digital technologies on performance depends heavily on implementation quality and organizational readiness (Kaewsaeng-on, 2024).

Table 7: Structural Model Results, Direct Effects and Bootstrapping Estimates of Path Coefficients

Hypotheses	**Original sample (O)**	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (|O/STDEV|)**	**P values**
H1: SCMP -> SCTA	-0.488	-0.488	0.074	6.631	0
H2: ITC -> SCTA	-0.092	-0.092	0.087	1.063	0.288
H3: SCC -> SCTA	0.036	0.036	0.05	0.725	0.468
H4: SCMP -> SCOP	-0.178	-0.178	0.067	2.661	0.008
H5: ITC -> SCOP	-0.111	-0.114	0.065	1.71	0.087
H6: SCC -> SCOP	0.739	0.741	0.039	18.98	0
H7: SCTA -> SCOP	-0.387	-0.388	0.057	6.731	0

The mediation analysis results presented in Table 8 provide further insights into the indirect effects of SCTA. The mediating effect of SCTA on the relationship between SCMP and SCOP is significant (β = 0.189, t = 4.344, $p < 0.001$), supporting H8 and indicating competitive partial mediation. This suggests that while SCMP negatively influences SCOP directly, it contributes positively to performance through technology adoption. This dual effect highlights the complex role of SCMP in both enabling and constraining performance outcomes, consistent with the TOE framework's emphasis on interaction effects among organizational and technological factors.

In contrast, SCTA does not mediate the relationships between ITC and SCOP (β = 0.036, t = 1.035, p = 0.301) or between SCC and SCOP (β = -0.014, t = 0.680, p = 0.496), leading to the rejection of H9 and H10. These findings indicate that the effects of ITC and SCC on performance are primarily direct rather than mediated through technology adoption. This suggests that while SCC strongly enhances performance independently, ITC may require additional enabling conditions to exert a significant influence.

Overall, the structural model results provide partial support for the proposed hypotheses and offer nuanced insights into the dynamics of supply chain performance in Beijing's cold storage industry. The findings validate key aspects of the TOE framework, particularly the

Table 8: Mediation Analysis Results of Supply Chain Technology Adoption in the Relationships between Supply Chain Management Practices, Information Technology Capabilities, Supply Chain Capabilities, and Supply Chain Operational Performance.

Total Effect			**Direct Effect**			**Indirect Effect**							**Hypothesis Result**
Coefficient	T value	P value	Coefficient	T value	P value	Hypothesis	Coefficient	SE	T value	P value	Percentile Bootstrap 95% CI		Type of Mediation
											LOWER	UPPER	
0.011	0.156	0.876	-0.178	2.661	0.008	H8: SCMP -> SCTA -> SCOP	0.189	0.043	4.344	0.000	0.113	0.284	Competitive Partial Mediation
-0.076	1.032	0.302	-0.111	1.710	0.087	H9: ITC -> SCTA -> SCOP	0.036	0.034	1.035	0.301	-0.030	0.105	No mediation
0.725	17.524	0.000	0.739	18.980	0.000	H10: SCC -> SCTA -> SCOP	-0.014	0.021	0.680	0.496	-0.060	0.021	No mediation

importance of organizational capabilities, while also revealing contextual limitations in the role of technology adoption. The results emphasize that successful performance improvement requires not only technological investment but also effective alignment of organizational practices and capabilities.

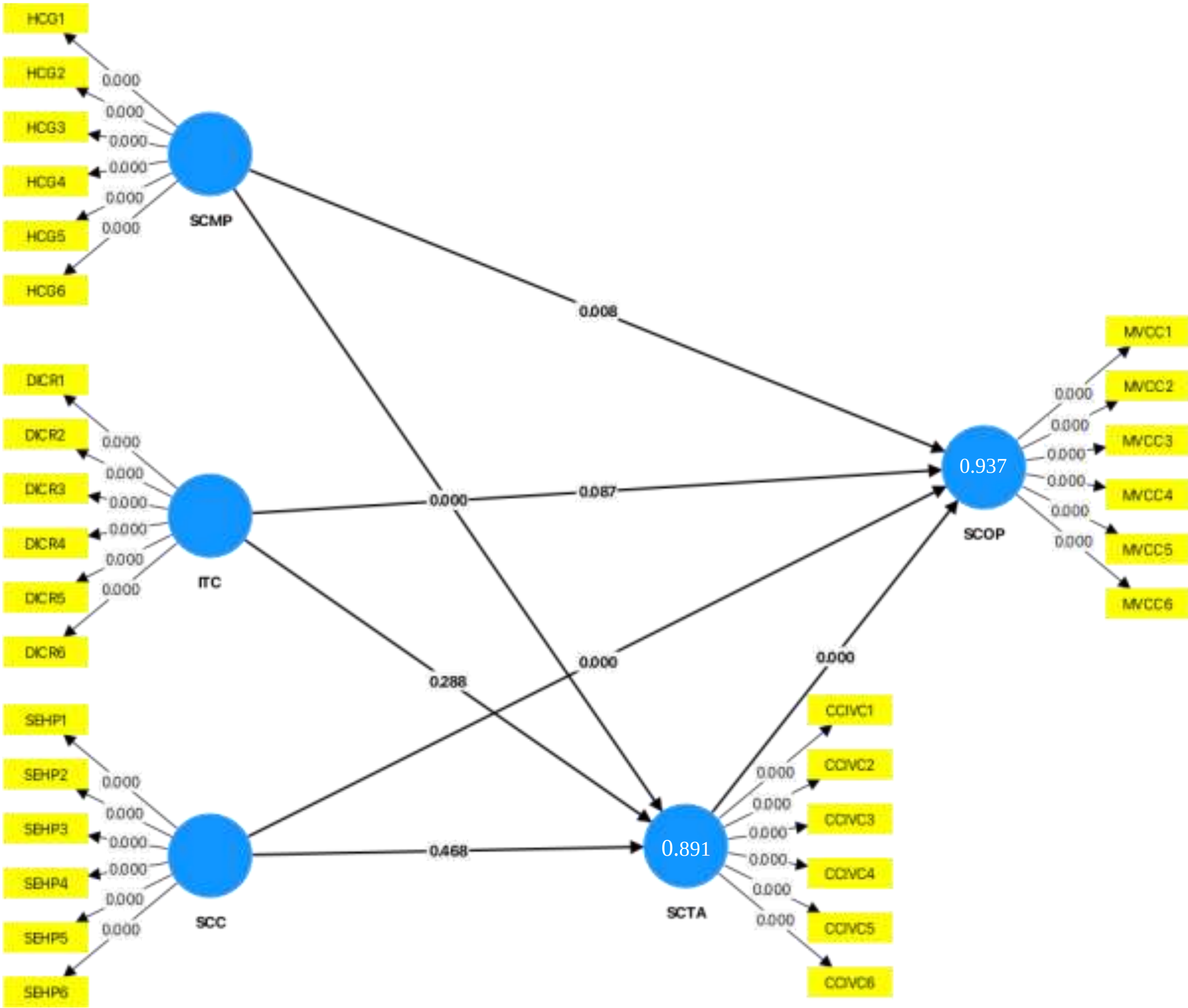

Figure 2: Structural Model Results of Supply Chain Management Practices, Information Technology Capabilities, and Supply Chain Capabilities on Supply Chain Operational Performance with the Mediating Role of Supply Chain Technology Adoption

Figure 2 presents the structural model results obtained from the PLS-SEM analysis, illustrating the relationships among supply chain management practices (SCMP), information technology capabilities (ITC), supply chain capabilities (SCC), supply chain technology adoption (SCTA), and supply chain operational performance (SCOP). The model demonstrates substantial explanatory power, with an R^2 value of 0.893 for SCTA and 0.939 for SCOP, indicating that the independent variables collectively explain a high proportion of variance in both the mediating and dependent constructs. The results further reveal that supply chain capabilities exert the strongest positive effect on SCOP, while supply chain management practices significantly influence both SCTA and SCOP, albeit with negative coefficients. Supply chain technology adoption also shows a significant relationship with SCOP, confirming its role within the model. In contrast, information technology capabilities exhibit non-significant effects on both SCTA and SCOP. The figure also reflects the significance levels (p-values) derived from bootstrapping, supporting the partial mediation effect of SCTA, particularly in the relationship between SCMP and SCOP. Overall, the findings indicate a well-fitted and robust model, providing empirical support for the Technology-Organization-Environment (TOE) framework in explaining supply chain performance dynamics in Beijing's cold storage industry.

5.0 Conclusion

This study investigated the impact of supply chain management practices (SCMP), information technology capabilities (ITC), and supply chain capabilities (SCC) on supply chain operational performance (SCOP), with the mediating role of supply chain technology adoption (SCTA) in Beijing's cold storage industry. Grounded in the Technology-Organization-Environment (TOE) framework, the study addressed the research problem of how organizational and technological factors interact to influence performance outcomes in a highly specialized and technology-dependent industry. The findings reveal that SCC is the most significant determinant of SCOP, while SCMP demonstrates both direct and indirect effects, and SCTA plays a partial mediating role, particularly in the relationship between SCMP and SCOP. In contrast, ITC does not exhibit significant direct or indirect effects, indicating that technological readiness alone is insufficient to enhance performance without effective integration and organizational alignment. The study contributes theoretically by extending the TOE framework through empirical validation in the cold storage context, highlighting the dominant role of organizational capabilities over technological factors. Methodologically, it applies PLS-SEM to examine complex mediation relationships, offering a robust analytical approach. Practically, the findings suggest that practitioners and policymakers should prioritize strengthening supply chain capabilities, improving organizational alignment, and ensuring effective implementation of digital technologies rather than merely investing in IT infrastructure. However, the study is subject to limitations, including its focus on a single geographical area (Beijing) and reliance on cross-sectional data, which may limit generalizability and causal inference. Future research is encouraged to explore longitudinal designs, incorporate additional contextual variables such as environmental and institutional factors, and extend the analysis to other regions or industries to enhance external validity.

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Declaration for competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

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