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The Impact of Digital Technology Adoption and Internationalization on Manufacturing Firms' Performance in China

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ABSTRACT

Emerging digital technologies are driving the digital transformation of manufacturing, reshaping global supply chains, and introducing new challenges. Existing research highlights the role of individual technologies, such as additive manufacturing, the Internet of Things, and big data analytics in increasing efficiency and flexibility in global operations. However, only a few studies have examined the collective impact of these technologies on firms' internationalization processes and performance, especially in emerging economies. This study addresses this gap by applying the Uppsala model to explore the links between digital technology adoption, internationalization, and performance. Survey data from 336 Chinese manufacturing firms, analyzed using structural equation modeling, indicate that both technology adoption and internationalization positively affect performance, with internationalization partially mediating this relationship. These findings underscore the importance of aligning digital technology adoption with internationalization strategies to enhance competitiveness, providing valuable insights for managers and policymakers on leveraging digital transformation for global success.

JEL Classification: F23, O33, L25, M16

Keywords: Industry 4.0; digital technology; degree of internationalization; Chinese manufacturing; firm performance

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INTRODUCTION

Industry 4.0 is reshaping business models, value-adding processes, and the meaning of international business by providing firms with global competitive advantages through digital technologies and emerging digital innovations, thereby enhancing organizational performance (Bhandari et al., 2023; Bhatti et al., 2022). These transformations are particularly urgent for Chinese manufacturing companies, which seek to reinforce their position in global value chains and harness digital technologies to achieve substantial performance gains. However, World Bank data indicates that while China's exports of goods and services peaked at $3.72 trillion in 2022, they fell to $3.52 trillion in 2023 (WBD, 2025). This decline indicates the challenges that Chinese manufacturing firms face in enhancing their performance in a globalized economy.

The emergence of digital technologies has led to fundamental changes in corporate systems and processes, management methods, and the workforce (Hervé et al., 2020). These technologies present both developmental opportunities and challenges for firms. For managers, understanding how digital technology adoption impacts a firm's international expansion and overall performance is crucial for navigating global competition and making informed decisions. Furthermore, the widespread adoption of digital technologies at the firm level is essential for advancing Industry 4.0, which is reshaping global economic systems and driving a more interconnected and advanced form of globalization (Lee et al., 2023).

Given the complex and uncertain global environment, coupled with the rapid advancement of digital technologies, it is crucial to investigate whether active participation in globalization and the adoption of digital technologies benefits the performance of Chinese manufacturing firms. This investigation offers managers key insights for developing strategic decisions about technology investments and global market expansion.

Over the past decade, international business researchers have extensively studied the Fourth Industrial Revolution (Industry 4.0) (Castagnoli et al., 2021; Lee et al., 2023; Rymarczyk, 2021; Strange and Zucchella, 2017). Industry 4.0 is expected to reshape global investment in terms of duration and geographical distribution (Niehoff et al., 2022) and to influence international business decisions, including location choices, network expansion, ownership roles, and strategic decisions for emerging multinational enterprises (Castagnoli et al., 2021). A firm's adoption of digital technology is a critical driver of its engagement with Industry 4.0 and its internationalization efforts. However, due to its recent emergence (Lee et al., 2023) and the lack of related information (Vadana et al., 2019), few studies focus on the role of digital technology in the enterprise internationalization process.

Most articles examining the impact of technology on internationalization focus on non-advanced technologies, such as cross-border e-commerce and digital platforms in international business activities. Relatively few studies have investigated the impact of emerging technology like big data analytics, blockchain, simulation, cybersecurity, augmented reality, and cloud computing (Sahoo et al., 2024). Furthermore, the limited number of international business studies have addressed specific advanced technologies, failing to encompass the full spectrum of technologies influencing internationalization (Ahi et al., 2021). Therefore, there exists a gap in the current international business literature, necessitating further exploration into the implications of digital technology adoption for firms' internationalization processes (Ahi et al., 2021; Wu and Vahlne, 2020), especially in emerging countries (Chauhan et al., 2021; Dalenogare et al., 2018; Hervé et al., 2020).

The manufacturing industry in China is particularly relevant for this study due to its pivotal role in the global economy and its rapid adaptation to Industry 4.0. As the largest manufacturing hub in the world, China has undergone significant transformations, driven by digital technologies that enhance efficiency and competitiveness. Previous studies often concentrated on developed economies (Bhatti et al., 2022), where the digital landscape, regulatory environments, and competitive pressures differ from those of emerging market economies (Kamble et al., 2018), especially in China.

For instance, while developed country firms may have mature digital infrastructures, Chinese manufacturers are increasingly leveraging digital technologies to innovate and compete globally. This unique context offers a valuable opportunity to examine how digital technology adoption influences internationalization and performance. Understanding these dynamics is essential for both academic inquiry and for practitioners and policymakers navigating the complexities of globalization and technological advancement in emerging markets.

Additionally, while the international business literature has extensively discussed and examined the relationship between the degree of internationalization and performance, empirical results remain inconsistent and contradictory (Ruigrok and Wagner, 2003; Singla and George, 2013), and there is still no complete understanding of this phenomenon (Marano et al., 2016). Some scholars argue that firm performance is not solely determined by the degree of internationalization but is also influenced by firm-specific advantages (FSAs). In this context, internationalization may act as an intermediate variable linking FSAs to firm performance (Nguyen, 2017; Nguyen and Kim, 2020; Rugman and Verbeke, 2008).

However, the international business literature has paid limited attention to the indirect relationship between FSAs, internationalization, and performance (Tashman et al., 2019), resulting in a lack of consistent empirical evidence on these relationships. For instance, Tashman et al. (2019) proposed that the degree of internationalization mediates the relationship between FSAs and firm performance. In contrast, Buckley and Tian (2017) argued that FSAs mediate the relationship between internationalization and performance, with internationalization having no direct effect on performance.

On the other hand, Lee et al. (2015) found a direct relationship between the degree of internationalization and performance but found no evidence supporting an indirect relationship. Further research is therefore needed to investigate the role of FSAs in shaping the relationship between the degree of internationalization and performance in the manufacturing sector, particularly in emerging markets.

This study aims to bridge these gaps in the literature by examining both the direct and indirect relationships between digital technology adoption, the degree of internationalization, and firm performance in the context of Chinese manufacturing firms. In the end, this study makes at least three contributions to the existing international business literature. Firstly, it examines the relationship between firm internationalization and performance in emerging markets, with a specific focus on medium-to-large firms. Through the 2017 version of the Uppsala model, this study extends the understanding of firm internationalization and performance in Chinese medium-to-large manufacturing firms, providing empirical support for the Uppsala model's application in the Chinese manufacturing context.

Secondly, in response to previous discussions on the role of multinationality in a firm's development (Nguyen and Kim, 2020; Rugman and Verbeke, 2008) and to gain a deeper understanding of the relationship between digital technology and international business, this study contributes by empirically testing the mediating role of degree of internationalization between digital technology adoption and performance. Thirdly, while previous international business studies have mainly applied internalization theory to comprehend firm internationalization, this study enhances the discussion by employing the Uppsala model to test the relationships between FSAs, the degree of internationalization, and performance in the emerging-market context, thus adding value to the development of international business theory.

Furthermore, given the limited empirical studies on the impacts of emerging digital technology on internationalization, this research provides practitioners and policymakers with valuable insights into the area of digital technology and the degree of internationalization. On one hand, this study furnishes empirical evidence regarding the influence of digital technologies on the extent of internationalization, aiding corporations and policymakers in comprehending the ramifications of digital technologies on global strategies. On the other hand, examining the mediating role of internationalization between digital technology adoption and firm performance grants policymakers a deeper understanding of the interplay between Industry 4.0 and international policies.

The remainder of this study is organized as follows: Section 2 reviews relevant theories to explain how digital technology adoption, as a key component of firm-specific advantages (FSAs), affects the degree of internationalization and firm performance. Section 3 discusses the hypotheses developed in this study. Section 4 describes the data collection procedures and operationalization of constructs. Section 5 presents detailed data analysis procedures and results. Section 6 discusses and summarizes the main research findings. The last section acknowledges the limitations of this research and offers recommendations for future studies.

LITERATURE REVIEW

Digital Technology Adoption

Firm-specific advantages (FSAs) hold a central position in international business literature and play a critical role in both internalization theory and the Uppsala model. Since Hymer's (1976) exploration of the "liability of foreignness," alongside Buckley and Casson's (1976) internalization theory and Dunning's (1977) eclectic paradigm, FSAs have emerged as a crucial determinant in a firm's internationalization process. Vahlne and Johanson (2017) emphasized that FSAs, originally conceptualized by Dunning and his colleagues (Dunning, 1977; Dunning and Rugman, 1985), encompass diverse asset-based elements. These elements include: privileged access to raw materials, capital, technology, brands, and distribution channels; transactional advantages such as robust governance systems, operational excellence, and management skills within internal multinational networks; and "soft" elements like relationships and organizational culture.

In the Uppsala model, "advantages" and "capabilities" are often used interchangeably (Vahlne and Johanson, 2017). It is widely accepted that firms must possess strong firm-specific advantages to overcome liabilities of foreignness and establish a sustainable presence in foreign markets. Furthermore, it is not individual FSAs, but rather the combined strength of the "advantage package," that matters. This study argues that digital technology adoption (DTA) is a key FSA within this package, particularly for manufacturing firms navigating the complexities of the Fourth Industrial Revolution. By developing relevant digital technologies, capabilities, and business models, firms can enhance their internal efficiencies, improve competitiveness, and strengthen their position in international markets (Lee et al., 2023).

Internalization Theory

The internalization theory, rooted in Coase's (1937) earlier work, posits that multinational enterprises exist to overcome the imperfect external market through internalizing market (Buckley, 2019; Rugman et al., 2011). Within this framework, FSAs play a pivotal role in shaping the internal market and become a key factor in the degree of internationalization-performance relationship (Kirca et al., 2011; Nguyen and Kim, 2020; Verbeke and Forootan, 2012) , albeit with different views on mediation models.

Some scholars argue that FSAs mediate this relationship (Buckley and Tian, 2017b; Verbeke and Forootan, 2012), as the degree of internationalization enhances FSAs, which in turn contribute to profitability. Buckley and Tian (2017b) justified this effect through two crucial mechanisms. First, knowledge generated by research and development (R&D) plays a pivotal role in the formation and development of multinational enterprises, and second, managers make rational choices about internationalization to maximize profits. Therefore, the degree of internationalization itself does not yield a direct financial return; rather, it benefits FSAs, indirectly influencing profits.

Conversely, other scholars propose that when performance is the dependent variable, the degree of internationalization should act as a mediating variable, with FSAs as the independent variable (Nguyen and Kim, 2020). In this view, FSAs promote internationalization and generate benefits through it. In other words, multinationality is a channel through which FSAs generate higher financial returns (Kirca et al., 2011). A higher degree of internationalization allows firms to leverage their FSAs more effectively, resulting in increased profitability in foreign markets due to broader market reach, revenue growth, and economies of scale (Tashman et al., 2019).

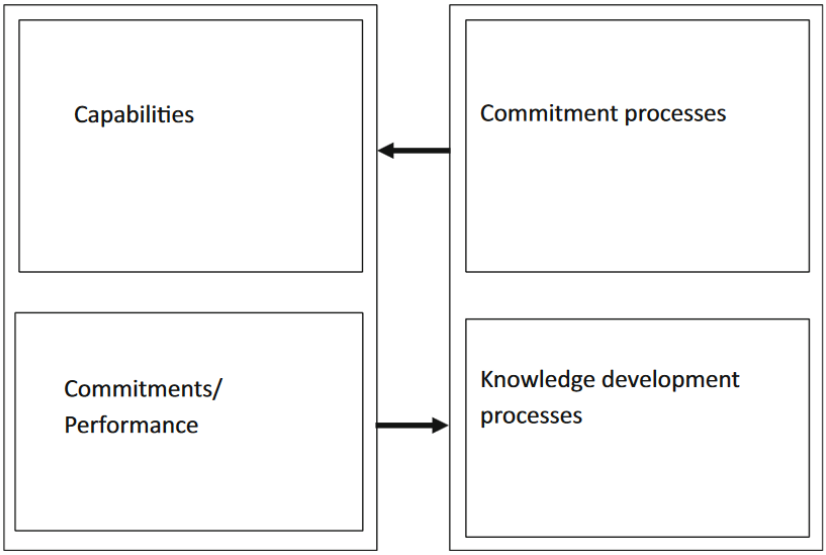
The Uppsala Model and Dynamic Capabilities Framework

While internalization theory provides a foundational explanation for the existence of MNEs, this study seeks to explore the digital technology adoption-degree of internationalization-performance relationship by integrating the Uppsala model with the dynamic capabilities framework. Drawing on Coase's transaction cost theory, the internalization of FSAs can also be understood through Penrose's resource-based view (Kirca et al., 2011), which forms the foundation of both the Uppsala model and dynamic capabilities framework.

Both frameworks propose that a firm's level of internationalization mediates the relationship between its FSAs and performance. According to the dynamic capabilities framework, markets must be created for new products and services that address unmet demand (Teece, 2019), and exchanges with local players depend on the firm- and country-specific advantages (Pitelis and Teece, 2010). Multinational enterprises leverage their

capabilities and co-specialization to engage and develop these markets, yielding returns. This process demonstrates that a firm's degree of internationalization is determined by its FSAs, with smaller firms being able to leverage strong dynamic capabilities to acquire the necessary ordinary capabilities when entering international market (Teece, 2014). Thus, firms can increase their degree of internationalization and enhance performance through FSAs.

In the context of the Uppsala model, Johanson and Vahlne (1990) emphasize that the internationalization process is a multilateral network development process. The business environment is seen as a network in which "no firm is an island," each firm is connected to numerous other entities through direct and indirect relationships (Johanson and Vahlne, 2009). The internationalization process thus involves co-evolution with network members (Vahlne and Johanson, 2019). Transitioning from an outsider to an insider provides the firm with the opportunity to act in its relationships with other firms (Johanson and Johanson, 2021), as insiders enjoy benefits that outsiders cannot access (Wu and Vahlne, 2020).



Source: Vahlne and Johanson (2017)

Figure 1 The Uppsala Model 2017

Indeed, the internationalization of a firm can be seen as entering a network or strengthening its position in a focal network (Wu and Vahlne, 2020). Firms need sufficient FSAs to establish a sustainable presence in foreign markets, overcoming liabilities of foreignness and outsidership (Vahlne and Johanson, 2017). Additionally, internationalization is one aspect of development opportunities emerging from the constant interaction of one or more relationships (Vahlne and Johanson, 2013). In a tightly-knit network, partners move together and co-evolve to form a more efficient production system, bringing benefits to internal partners through that network (Vahlne and Johanson, 2021).

The 2017 Uppsala model incorporates the concept of dynamic capabilities into its framework, which is reflected in the "Capabilities" section in the upper left part of Figure 1. Johanson and Vahlne (2017) mentioned that a capabilities (interchangeable with firm-specific advantages)—dynamic or operational—reflects the ability to use resources for a particular purpose. This integration highlights how firms develop and utilize capabilities to navigate international markets effectively.

In this study, digital technology adoption is considered a crucial FSA, driving degree of internationalization by improving a firm's global competitiveness. It not only enhances a firm's degree of internationalization but also directly impacts performance through innovation and operational efficiency. The Uppsala model's emphasis on a gradual and incremental approach to internationalization, where firms gain experiential knowledge and develop capabilities within their networks, is particularly relevant for understanding how digital technology adoption facilitates this process, especially in the context of emerging markets like China.

As firms adopt digital technologies, they accumulate knowledge and commitments within their business networks, which increases their degree of internationalization. This is in line with the Uppsala model's focus on network development and relationship building, where digital technologies enable firms to better manage international networks, adapt to foreign market conditions, and enhance their competitive positions (Bhatti et al., 2022).

By extending the Uppsala model, this study demonstrates that digital technology adoption not only contributes directly to firm performance but also enhances the degree of internationalization, mediating the relationship between the two. The empirical results of this research provide support for the Uppsala model's gradual internationalization approach, showing that digital technologies enhance firms' network positions and knowledge accumulation, ultimately improving performance in foreign markets (as shown in Figure 2).

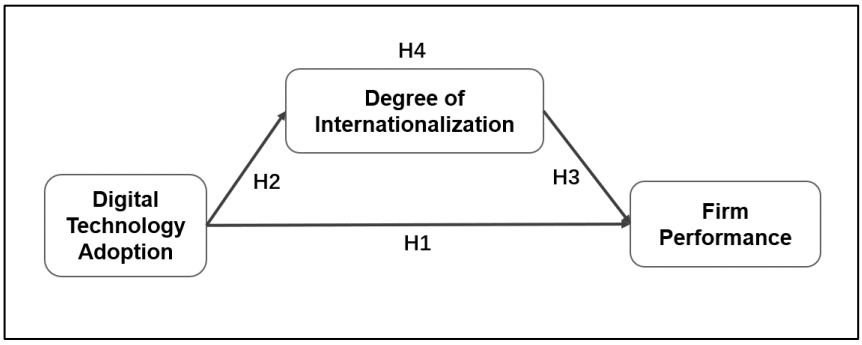


Figure 2 Theoretical Model

HYPOTHESIS DEVELOPMENT

Figure 2 presents the theoretical framework and hypotheses of this study, which are explained in the following sub-sections.

Digital Technology Adoption and Firm Performance

The growth of the manufacturing industry is closely tied to technological advancements, especially in countries like China, where manufacturing is a key economic driver. Digital technologies, encompassing the Internet of Things (IoT), cloud computing, artificial intelligence, big data analytics, and augmented reality, contribute to the enhancement of firms' productivity and servitization when integrated with traditional technologies (Frank et al., 2019), ultimately resulting in elevated firm performance.

Studies in developed countries have shown the positive impact of digital technologies on performance. For example, Naglič et al. (2020) found that in Slovenian export firms, big data analytics and IoT improve managers' ability to respond to customer needs, boosting performance. Similarly, Eslami et al. (2021) concluded that Industry 4.0 technologies enhance supply chain agility and financial performance in Swedish firms. Bettiol et al. (2022) demonstrated that in Italy, the combination of ICT and Industry 4.0 technologies positively influences knowledge-related performance, such as product development and customer engagement.

However, most existing literature focuses on developed countries, leaving a gap in understanding how digital technologies can improve performance in China's manufacturing sector. Chinese manufacturing firms are increasingly integrating traditional technologies with digital technologies such as AI and blockchain. Li et al. (2022) found that digitalization improves performance in Chinese manufacturing firms, this effect can be moderated by knowledge inertia and organizational integration mechanisms. This study seeks to fill the gap by exploring how digital technology adoption impacts performance in Chinese manufacturing firms and proposes the following hypothesis:

H1: Digital technology adoption has a positive impact on firm performance.

Digital Technology Adoption and Degree of Internationalization

The Uppsala model emphasizes that technology development capabilities are integral to internationalization processes (Vahlne and Ivarsson, 2014). The adoption of digital technology empowers enterprises to reconsider their business models and existing capabilities, facilitating more effective international expansion (Bhatti et al., 2022). However, previous studies have not fully captured the impact of emerging digital technology adoption on the degree of internationalization in Chinese manufacturing firms. Most existing research focuses on developed economies and examines how technology affects exports. For example, studies have explored the influence of digital technology on firms' export propensity (Cassetta et al., 2020) or the impacts of blockchain, big data, and artificial intelligence on digital exports (Elia et al., 2021).

As advanced digital technology emerges as a dominant trend, they are reshaping the business landscape (Reis et al., 2020) and redefining international competition (Matarazzo et al., 2021). Digital technology enables organizations to enhance supply chain efficiency by facilitating the sharing and utilization of resources and information, making firms more adaptable to management directives and prevailing economic conditions (Belhadi et al., 2022). Technologies such as blockchain and big data analytics also assist firms in tracking and managing information within global logistics networks. Consequently, digital technology adoption is proposed as a crucial factor positively influencing the degree of internationalization of emerging-market manufacturing firms. The following hypothesis was thus formulated:

H2: Digital technology adoption has a positive impact on a firm's degree of internationalization.

Degree of Internationalization and Firm Performance

According to internalization theory, the relationship between the degree of internationalization and firm performance is contingent on factors such as multinationality, firm strategic motivations, industry characteristics, and home-country conditions (Kirca et al., 2011). In general, internationalization is viewed as beneficial to firms (Contractor, 2007), with higher degrees of internationalization tending to yield more advantages than costs for the firm. Drawing from the Uppsala model, firms accrue knowledge and enhance FSAs throughout the internationalization process (Vahlne and Johanson, 2017).

Empirical research on Korean firms (Lee et al., 2015) and Malaysian firms (Juniati et al., 2019) suggests that Asian firms generally derive more benefits than costs from expanding into international markets, indicating a positive outcome in the internationalization process. However, the extent to which this relationship holds true for emerging-market firms, particularly in China's rapidly evolving digital economy, remains underexplored. This study addresses this gap by analyzing the specific impact of degree of internationalization on firm performance in Chinese manufacturing firms. Based on this, the following hypothesis is proposed:

H3: The degree of internationalization has a positive impact on firm performance.

The Mediating Role of Degree of Internationalization

Prior research suggests that degree of internationalization mediates the relationship between FSAs and firm performance in various industries. For example, an empirical study on U.S. firms in the movie studio industry found a co-evolution between FSAs and the degree of internationalization, with each factor mediating the positive effect of the other on performance (Tashman et al., 2019). In the digital economy, manufacturing firms are compelled to transform their business models to generate increased profits through digital technology (Singh et al., 2021).

However, most of these studies have been limited in scope, focusing predominantly on developed economies and industries outside the manufacturing sector. This study aims to address this gap by investigating the manufacturing industry in China, where firms are increasingly adopting digital technologies to accelerate internationalization and enhance performance. Similar to how blockbuster production capabilities serve as a key FSA in the movie industry (Tashman et al., 2019), digital technology adoption is considered a pivotal FSA in the manufacturing sector.

Both the Uppsala model and dynamic capabilities framework assert that a firm's capabilities are fundamental to its internationalization process and performance. Nguyen and Kim (2020) further argue that the degree of internationalization serves as an intermediate mechanism between a firm's set of FSAs and its performance. Therefore, this research posits the following hypothesis:

H4: The degree of internationalization mediates the relationship between digital technology adoption and firm performance.

RESEARCH METHODOLOGY

This study employed a deductive, quantitative research method, utilizing an online questionnaire for data collection. Data were analyzed using SPSS 23 and SmartPLS 4 software.

Data and Sample

The population under investigation comprised large and medium-sized international manufacturing enterprises in China. Two approaches were employed to determine the minimum sample size. The first approach used G*Power 3.1 software, configured for an F-test linear multiple regression, with a two-tailed design, two quantitative predictor variables, an effect size of 0.15, a margin of error of 5%, and a statistical power (1-β) of 80%. With these parameters, this method determined the minimum sample size for the study to be 68. The second approach was the inverse square root method, as suggested by Hair et al. (2021). Setting the statistical power (1-β) at 80%, significance level at 5%, and the minimum value of the path coefficient at 0.15, the calculated minimum sample size was 275. Given the study's focus on manufacturing firms with basic experience in international business and Industry 4.0, a sample size of 275 was thus deemed sufficient.

The unit of analysis for this study was large and medium-sized manufacturing companies in China. The study targeted publicly listed manufacturing firms that were actively engaged in internationalization efforts. To ensure the collection of relevant and reliable data, respondents were required to have worked at their firms for at least one year and to hold mid- to senior-level management positions, ensuring they possessed sufficient knowledge about the company’s international operations and strategic decisions.

Besides that, simple random sampling was employed to select 1,200 companies from the list of Chinese A-share manufacturing firms in the China Securities Regulatory Commission (CSRC). The data collection period extended from April 11, 2023, to June 10, 2023. A total of 1,200 questionnaires were distributed, of which 422 questionnaires were returned, resulting in a response rate of 35.17%. After screening for outliers and missing values, 336 questionnaires were considered suitable for analysis in this study.

Measurement of Variables and Scales

In this study, measurement items were either adopted or adapted from prior literature to align with the specific context of Chinese manufacturing firms. Firm performance refers to the outcomes of a firm's activities and its network position (Vahlne and Johanson, 2017). The items used to measure firm performance were adapted from Gastaldi et al. (2022).

The degree of internationalization (DOI) was assessed using items adapted from Hojnik et al. (2018). While Hojnik et al. (2018) originally proposed three items to measure firms’ internationalization, only two items were retained in this study. The third item (mode of operation) was excluded, as it was deemed less relevant to the internationalization processes of Chinese manufacturing firms." Additionally, minor wording adjustments were made to ensure clarity for respondents within the Chinese business environment.

In alignment with the discussions on digital technology within the context of Industry 4.0 (Agostini and Nosella, 2019; Castagnoli et al., 2021), this study identified 11 digital technologies: additive manufacturing, advanced robotics, artificial intelligence, augmented reality, blockchain, big data and analytics, cloud computing, cybersecurity, horizontal and vertical system integration, the Internet of Things, and simulation tools.

The measurement of digital technology adoption (DTA) followed a two-stage approach. In the first stage, respondents indicated whether their firm required each of the 11 technologies by selecting 'no' or 'yes.' Technologies marked 'no' were excluded from further evaluation, as they were considered irrelevant to the

firm's digital strategy. In the second stage, for each technology marked 'yes,' respondents rated the level of adoption using a five-point Likert scale ranging from 'not adopted' (1) to 'fully adopted' (5). This approach distinguished between technologies deemed relevant and those actively adopted by firms.

Finally, a single-item composite score for DTA was constructed. Since different firms require different subsets of the 11 technologies, the final Digital Technology Adoption score was calculated by averaging the five-point ratings of the technologies deemed necessary. For instance, if a firm identified five relevant technologies, the mean rating of those five technologies constituted the single composite indicator. This method captures the extent of digital technology adoption in alignment with each firm's specific requirements.

DATA ANALYSIS AND RESULTS

Partial least squares structural equation modeling (PLS-SEM) was performed using the SmartPLS 4 software to analyze the data and test the hypotheses. PLS-SEM analysis involves two stages: assessment of the measurement model and assessment of the structural model. Before conducting this analysis, the study addressed concerns related to bias, as detailed below.

Non-Response and Common Method Bias

This study examined non-response bias by conducting an independent samples t-test, comparing the means of each variable between early responders (top 50% of responders) and late responders (bottom 50% of responders). The results revealed no significant differences in the mean values of the variables between the two responder groups, as all p-values were greater than 0.05. Consequently, it was inferred that non-response bias did not affect the data collected in this study.

To mitigate common method bias, the study implemented several methods. Firstly, following the recommendations of Podsakoff et al. (2003, 2012), the questionnaire included clear instructions, assured respondents of the confidentiality and anonymity of their responses, and employed a diversified survey scale format to measure performance, degree of internationalization, and digital technology adoption.

After data collection, Harman's single-factor test was employed to examine common method bias due to its wide usage (Jordan and Troth, 2020; Podsakoff et al., 2003). The test results indicated that the first factor accounted for 32.19% of the total explained variance, which falls below the 50% threshold. These findings suggest that common method bias was not a significant concern in this study (Kock et al., 2021).

Measurement Model Evaluation

Following the guidelines of Hair et al. (2021), this study evaluated both the validity and reliability of the measurement model. In this model, firm performance was specified as a reflective variable, while the degree of internationalization (DOI) and digital technology adoption (DTA) were specified as formative variables.

Reflective Measurement Model

As shown in Table 1, the indicator loadings for firm performance exceeded 0.754, surpassing the recommended threshold of 0.708. This demonstrates satisfactory indicator reliability for the reflective construct. Next, internal consistency reliability was assessed using Cronbach's alpha, composite reliability (ρc), and composite reliability (ρA) (Hair et al., 2019). Firm performance yielded a Cronbach's alpha of 0.762, a composite reliability (ρc) of 0.861, and a composite reliability (ρA) of 0.786, all of which met recommended criteria. Hence, internal consistency reliability for the reflective construct was confirmed. In addition, convergent validity was deemed acceptable, as the average variance extracted (AVE) for firm performance was 0.675, exceeding the minimum requirement of 0.50.

Table 1 Validity and Reliability of Reflective Indicators

Construct	Items	Indicator Loading	Cronbach's Alpha	Composite Reliability (ρa)	Composite Reliability (ρc)	Average Variance Extracted (AVE)
Firm Performance (FP)	FP1	0.870	0.762	0.786	0.861	0.675
	FP2	0.837				
	FP3	0.754				

To evaluate discriminant validity, this study followed the guidelines of Hair et al. (2020) and Henseler et al. (2015) by using the heterotrait-monotrait ratio (HTMT) approach. As indicated in Table 2, the HTMT value was 0.431, which is well below the threshold of 0.85, thereby confirming discriminant validity for the reflective model.

Table 2 Discriminant Validity Using the HTMT Criterion

	DTA	FP
DTA		
FP	0.431	

Note: DTA= Digital technology adoption; FP=Firm's performance.

Formative Measurement Model

Because the degree of internationalization was modeled as a formative variable, and digital technology adoption was measured using a single-item composite score, this study assessed convergent validity, collinearity, and the significance and relevance of the formative indicators Hair et al. (2020, 2021). To evaluate convergent validity, redundancy analyses were performed by correlating the degree of internationalization with its alternative single-item measures of the same construct. The analysis yielded a correlation of 0.759 for the degree of internationalization. Similarly, the correlation between digital technology adoption and its alternative variables was 0.744. These results confirm that both variables satisfy the requirements for convergent validity.

Table 3 Formative Indicator Weights and VIF

Construct	Items	Indicator Weights	p-value	VIF
Degree of Internationalization (DOI)	**DOI1**	0.784	0.000	1.499
	DOI2	0.315	0.019	1.499

Subsequently, multicollinearity in the formative model was examined using the Variance Inflation Factor (VIF). All formative indicators exhibited VIF values below 1.754, which is well under the recommended cutoff of 3.0 (Hair et al., 2020), suggesting that collinearity was not problematic. Finally, the significance and relevance of the formative indicators were evaluated based on their indicator weights (Hair et al., 2020). As presented in Table 3, the bootstrapping results showed that the indicator weights for the degree of internationalization were significant ($p < 0.05$), indicating that each indicator meaningfully contributed to the construct.

Structure Model Evaluation

Following the suggestions of Hair et al. (2020), it was confirmed that collinearity was not an issue in the structural model, as the VIF values for all constructs were less than 3.0. Subsequently, the significance and relevance of the relationships within the structural model were evaluated through a bootstrapping procedure.

Table 4 Path Coefficient Analysis and VIF

Relationship	Path Coefficient	Standard Deviation	t-value	p-value	2.50%	97.50%	Decision	VIF
DTA → FP	0.314	0.058	5.410	0.000	0.197	0.420	Support	1.221
DTA → DOI	0.425	0.039	10.950	0.000	0.343	0.497	Support	1
DOI → FP	0.162	0.060	2.721	0.007	0.041	0.274	Support	1.221
DTA → DOI → FP	0.069	0.026	2.665	0.008	0.018	0.119	Partial Mediation	

Note: DOI=Degree of internationalization; DTA=Digital technology adoption; FP=Firm performance.

The results presented in Table 4 indicate that all hypotheses were statistically significant at the 95% confidence level. Specifically, digital technology adoption demonstrated a positive impact on firm performance (β=0.314) and the degree of internationalization (β=0.425). Furthermore, the degree of internationalization demonstrated a positive impact on firm performance (β=0.162). Notably, this study's results suggest that the degree of internationalization mediates the relationship between digital technology adoption and firm performance (β=0.069). Since both the direct and indirect relationships share the same direction, the degree of internationalization plays a complementary mediation (partial) role between digital technology adoption and firm performance. Therefore, all the research hypotheses (H1 to H4) were supported.

Table 5 Model's Explanatory Power

Endogenous Construct	R2	R-square adjusted	Q^2predict
DOI	0.181	0.178	0.173
FP	0.168	0.163	0.140

Note: DOI=Degree of internationalization; FP=Firm performance.

The R^2 is the coefficient of determination, which measures the in-sample prediction of all endogenous constructs (Hair et al., 2020). R^2 values of 0.75, 0.50 and 0.25 can be considered substantial, moderate and weak (Hair et al., 2021). Both R^2 values for the degree of internationalization (R^2=0.181) and firm performance (R^2=0.168) indicated weak explanatory power (see Table 5).

Table 6 Model's Predictive Power

Indicators	Q^2predict	PLS-SEM_RMSE	LM_RMSE
DOI1	0.164	1.308	1.308
DOI2	0.104	1.32	1.320
FP1	0.109	0.966	0.966
FP2	0.117	0.968	0.968
FP3	0.053	0.976	0.976

Note: DOI=Degree of internationalization; FP=Firm performance; LM=Linear model; RMSE=Root mean square error.

The model's predictive power was further assessed through predictive relevance (Q^2) and Q^2predict, following the procedure outlined by Shmueli et al. (2019). To meet the recommended minimum size for the holdout sample (N=30), this study set 10 folds (k = 10), and 10 repetitions for a holdout sample of 33. The Root Mean Squared Error (RMSE) is suitable for comparing prediction errors due to its highly symmetric distribution. The results in Table 6 indicate that only one of the five indicators' PLS-SEM RMSE values was smaller than the linear model's RMSE value. Based on the guidelines of Shmueli et al. (2019), this study's model was concluded to have medium predictive power.

Robustness Test

According to the suggestions of Hair et al. (2019), a robustness test with nonlinear effects, endogeneity, and unobserved heterogeneity was applied. Nonlinearity can impact the strength of the relationship between variables, potentially leading to incorrect theoretical results. To assess the nonlinearity effect, the quadratic effect was measured by introducing additional variables for each construct. The significance of these quadratic effects was tested using percentile confidence intervals obtained from bootstrapping, with 10,000 subsamples and a 5% significance level. The results in Table 7 show that all constructs' quadratic effects were statistically insignificant. Therefore, nonlinearity was not an issue for this study.

Table 7 Constructs' Quadratic Effects

	Path Coefficient	t-value	p-value	2.50%	97.50%
QE (DTA) -> DOI	0.019	0.504	0.614	-0.052	0.092
QE (DTA) -> FP	-0.038	0.946	0.344	-0.114	0.040
QE (DOI) -> FP	-0.031	0.778	0.437	-0.111	0.045

Note: DOI=Degree of internationalization; DTA=Digital technology adoption; FP=Firm performance; QE=Quadratic effect.

As endogeneity problems may arise in the relationship between the degree of internationalization (DOI) and firm performance (Buckley and Tian, 2017a), it was essential to assess endogeneity in this study. The systematic procedure proposed by Hult et al. (2018) to evaluate endogeneity. Based on the Kolmogorov–Smirnov test results, it is shown that all constructs were non-normally distributed, fitting the Gaussian copula requirements. Additionally, Gaussian copula variables were created for each relationship and tested individually using bootstrapping. None of the Gaussian copula variables yielded significant results ($p > 0.05$), indicating that endogeneity was not an issue in this study.

Table 8 Segment Information Criteria Analysis

	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
AIC (Akaike's information criterion)	1788.24	1777.25	1774.17	1767.42	1766.03
AIC3 (modified AIC with Factor 3)	1793.24	1788.25	1791.17	1790.42	1795.03
AIC4 (modified AIC with Factor 4)	1798.24	1799.25	1808.17	1813.42	1824.03
BIC (Bayesian information criterion)	1807.32	1819.24	1839.06	1855.22	1876.73
CAIC (consistent AIC)	1812.32	1830.24	1856.06	1878.22	1905.73
HQ (Hannan-Quinn criterion)	1795.84	1793.99	1800.04	1802.42	1810.16
MDL5 (minimum description length with factor 5)	1923.66	2075.19	2234.63	2390.39	2551.52
LnL (LogLikelihood)	-889.12	-877.62	-870.09	-860.71	-854.02
EN (normed entropy statistic)	0.00	0.33	0.57	0.60	0.61
NFI (non-fuzzy index)	0.00	0.36	0.51	0.52	0.50
NEC (normalized entropy criterion)	0.00	225.48	146.06	135.65	131.42

According to the systematic procedure outlined by Hair et al. (2018), the FIMIX-PLS approach was employed to examine unobserved heterogeneity. Given that the minimum sample size required for this study was 68, five segments were tested (N = 336 / 68 = 5). Table 8 displays the results of FIMIX-PLS with a stopping criterion of 10^{-5}, a maximum number of iterations of 5000, and 10 repetitions.

According to Hair et al. (2018), FIMIX-PLS uses likelihood-based information criteria to determine the optimal number of segments by balancing model fit and the number of parameters. A smaller information criterion value indicates a better solution. Hair et al. (2018) suggest that AIC3 and CAIC should be considered together, as their agreement often indicates the correct number of segments. AIC4 and BIC also perform well, while AIC tends to overestimate, and MDL5 tends to underestimate the number of segments. In this study, the minimum values of AIC4, BIC, and CAIC indicated that Segment 1 was most appropriate, meaning unobserved heterogeneity was not a major issue.

DISCUSSION

The statistical findings of this study provide support for H1, indicating a positive impact of digital technology adoption on firm performance (β=0.314, P<0.05). This result aligns with prior studies while expanding the existing literature by focusing on large and medium-sized international Chinese manufacturing firms, a sector less examined in previous research. For instance, a study involving 335 SMEs in Bangladesh highlighted a strong positive correlation between cloud computing adoption and firm performance (Khayer et al., 2020). Similarly, evidence from 320 UK managers demonstrated that the adoption of big data technology positively influences organizational value creation (El-Haddadeh et al., 2021). While these studies emphasize specific technologies, this research demonstrates how adopting a broader range of digital technologies collectively enhances firm performance in China's rapidly evolving industrial landscape, offering new insights into their comprehensive impact in a developing economy context.

The results also support H2, indicating that digital technology adoption positively impacts the degree of internationalization (β=0.425, P<0.05). This suggests that greater adoption of digital technologies facilitates international expansion for Chinese manufacturers, thereby filling the gap in empirical studies related to emerging markets. This finding aligns with empirical evidence emphasizing the pivotal role of digital technology as a driver of firm internationalization, as observed in studies on Italian SMEs, which demonstrated a positive association between digital technology a firm's export propensity (Cassetta et al., 2020).

Moreover, certain digital technologies have been identified in past empirical evidence as positively influencing the degree of internationalization. Findings from Italy indicate that firms adopting digital technologies such as smart logistics, blockchain, big data, and artificial intelligence are positively associated with digital export (Elia et al., 2021). Additionally, empirical evidence on Italian medium-sized enterprises suggests that big data analytics capability significantly impacts the degree of internationalization (Bertello et al., 2021). Thus, this study reinforces the critical role of digital technologies in enhancing internationalization for Chinese firms, bridging the knowledge gap between digitalization and global expansion in emerging markets.

Support for H3 indicates a statistically significant positive relationship between the degree of internationalization and firm performance (β=0.162, P<0.05). While previous research has yielded inconsistent and contradictory findings on this relationship (Marano et al., 2016), this study aligns with

evidence suggesting that internationalization positively influences corporate value, such as in Korean firms (Lee et al., 2015). This corroboration supports the notion that Chinese manufacturing firms generally accrue more benefits through the internationalization process.

Additionally, previous empirical studies have identified varying benefits and costs associated with different degrees of internationalization, resulting in non-linear relationships. For instance, research has revealed a horizontal S-curve relationship for large firms, a negative linear relationship for small firms, and a U-shaped relationship for medium-sized firms in Spain (Benito-Osorio et al., 2016). In Cameroon, a W-shaped relationship was observed (Phan et al., 2020). These findings underscore the heterogeneity of internationalization outcomes and the diverse benefits and costs firms may experience (Contractor, 2012).

The results for H4 demonstrate that internationalization mediates the relationship between digital technology adoption and firm performance. Both the direct ($\beta = 0.314$, $p < 0.05$) and indirect ($\beta = 0.069$, $p < 0.05$) effects were statistically significant and in the same positive direction, constituting complementary partial mediation (Hair et al., 2021). This highlights a key contribution of the study, as it provides empirical evidence on how digital technology facilitates internationalization, which in turn amplifies its impact on firm performance.

While previous studies have acknowledged the positive effects of some digital technologies on both internationalization and firm performance (Ahi et al., 2021; Castagnoli et al., 2021). this study extends the literature by demonstrating how these effects are interlinked in Chinese manufacturing firms, a context that has been underexplored. The findings indicate that by leveraging digital technologies, firms can effectively manage their international operations, thereby boosting both their international reach and overall performance. This underscores the strategic importance of digital technology adoption, especially in industries and regions where international expansion is critical for growth.

For example, empirical evidence from the U.S. movie studio industry suggests that FSAs support performance through internationalization (Tashman et al., 2019). In line with this, the present study identifies digital technology as one of the key FSAs that enhances the performance of Chinese manufacturing firms on the international stage. This contribution provides a clearer understanding of how digital technology, as a modern FSA, directly facilitates both internationalization and performance outcomes in manufacturing contexts.

The results align with the theoretical foundations of the Uppsala model and the dynamic capabilities framework, which propose that FSAs drive firm performance and that the degree of internationalization serves as an intermediary mechanism. Case studies further illustrate these dynamics. For example, the Chinese manufacturing firm Gree expanded into emerging markets (e.g., Brazil, Vietnam, and Cambodia) by establishing production plants and transferring advanced technologies to local subsidiaries, enhancing profits through internationalization (Wu and Vahlne, 2022). Similarly, the German multinational Delivery Hero leveraged digital technology to expand internationally, resulting in increased revenue generation (Bhatti et al., 2022).

In summary, the international market provides a platform for firms to develop, deploy, and exploit digital technologies and other FSAs, generating greater benefits than focusing solely on domestic operations. Although Chinese manufacturing firms may encounter barriers and risks during international processes, emerging digital technology supports firms in overcoming or mitigating those challenges, ultimately enhancing the performance of Chinese manufacturing firms.

Implications

The results of this study provide several key implications for practitioners and policymakers in the context of Chinese manufacturing enterprises. First, digital technologies adoption has a direct and significant impact on firm performance (H1), highlighting the need for managers to invest in advanced digital technologies such as artificial intelligence, cloud computing, and big data analytics that align with their firms' strategic goals. These technologies can improve operational efficiency, innovation, and competitiveness, providing effective tools for companies' digital transformation and competitiveness enhancement. From a policy perspective, governments encouragement of technology investment is beneficial to the transformation and development of China's manufacturing industry.

Second, the adoption of digital technologies promotes internationalization (H2), further proving that technologies such as smart logistics, the Internet of Things, and blockchain facilitate entry into and expansion

within global markets. Managers with internationalization needs should focus on integrating these technologies to streamline cross-border operations and gain competitive advantages internationally. policymakers can strengthen digital infrastructure, such as secure data networks and high-speed connectivity, to support technology-driven firms in expanding into global markets.

Third, the degree of internationalization has a positive impact on firm performance (H3), emphasizing that entering international markets is a strategic move for Chinese manufacturers. Developing-market country companies can improve their performance by taking advantage of global opportunities, and combining internationalization with digital technology adoption can further amplify these benefits. Governments can help by establishing favorable trade agreements and export support policies that enable firms to thrive in international markets.

Finally, the study highlights that the degree of internationalization mediates the relationship between digital technology adoption and performance (H4), suggesting that while digital adoption directly improves performance, global expansion amplifies this effect. Managers can improve firm performance through efficient digital transformation and internationalization. Policymakers should ensure that technology innovation policies are aligned with internationalization support to help firms fully leverage their digital investments globally.

In short, the interplay between digital technology, internationalization, and firm performance provides a dual focus for managers and policymakers. Managers should adopt strategies that combine digital technologies with international market expansion, while governments must support these efforts through targeted policies that promote technological advancement and global trade.

Limitation and Future Study

While this study makes valuable theoretical and practical contributions to existing research and practice, it is not without limitations. The first limitation arises from the sample characteristics, as the study focused exclusively on A-share listed Chinese manufacturing companies. While this aligns with the study's objectives of represents large and medium-sized Chinese manufacturing enterprises, it limits the generalizability of the findings to other contexts, particularly smaller firms and those from non-manufacturing sectors.

The development of Industry 4.0 is a global phenomenon. However, this study focuses exclusively on the development of digital technology and internationalization in China, limiting its scope in addressing broader Industry 4.0 and internationalization trends in other emerging economies. Future research could enhance generalizability by testing this model in different countries and industries.

The second limitation is related to the use of a cross-sectional dataset, which cannot capture the internal change processes of individual firms as they use digital technology to expand their international market and improve their performance. Longitudinal studies are recommended for future research to explore these processes in depth and provide a clearer understanding of the temporal dynamics at play. Additionally, empirical evidence regarding the relationship between FSAs, the degree of internationalization, and firm performance remains limited. Future research could explore these relationships in greater depth. For example, investigating how various types of FSAs, beyond just digital technology, influence internationalization and performance, and how these advantages may have distinct effects in both regional and international markets, would provide valuable insights.

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APPENDIX

Appendix A Measurement Item

Constructs	Measurement Items	Scale
Degree of Internationalization (DOI)	**Number of foreign markets** None at the moment 1–3 foreign markets 4–5 foreign markets 6–10 foreign markets 11–15 foreign markets 16–20 foreign markets 21 or more foreign markets **Share of sales abroad** No sales on foreign markets Between 1 and 20% Between 21 and 30% Between 31 and 50% Between 51 and 70% Between 71 and 90% Between 91 and 100%	Seven-point Likert-type scale (categories as shown on the left)
Overall degree of internationalization	**Please assess the firm's overall degree of internationalization.**	Seven-point Likert-type scale "1 = Very low" to "7 = Very high"
Firm Performance (FP)	**Compared to your main competitor over the past three years, please rate your firm's performance in terms of:** Net profit Profit growth Return on sales	Five-point scale ("1 = Much lower" to "5 = Much higher")
Need for Digital Technologies	**Please indicate whether the company has a need to use the following technologies:** Additive manufacturing Advanced Robotics Artificial intelligence Augmented reality Blockchain Big data and analytics Cloud computing Cybersecurity Horizontal and vertical system integration Internet of Things Simulation tools	Yes/No
Level of Adoption of Digital Technologies	**Please assess the adoption level of selected technology.** Additive manufacturing Advanced Robotics Artificial intelligence Augmented reality Blockchain Big data and analytics Cloud computing Cybersecurity Horizontal and vertical system integration Internet of Things Simulation tools	Five-point Likert-type scale "1 = Not adopted" to "5 = Fully adopted"
Overall level of digital Adoption	**Please assess the overall level of adoption of all the above digital technologies.**	