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How Does Digital Technology Innovation Affect the Internationalization Performance of Chinese Enterprises? The Moderating Effect of Sustainability Readiness

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Abstract: The existing literature highlights the role of digital technology innovation in driving the international performance of enterprises. However, it has largely overlooked the nonlinear relationships that emerge from their quest for contributing towards global sustainable development goals. Our study explores the nonlinear influence of digital technology innovation on firms' international performance, further investigating how this relationship may be moderated by sustainability readiness, as measured through sustainable technological capabilities and sustainable certification standards. Using a double fixed effects model on a sample of 269 Chinese listed digital enterprises from 2012 to 2019, our findings reveal a U-shaped relationship between digital technology innovation and internationalization performance, which is more pronounced for firms with superior sustainable technological capabilities. However, the influence of sustainable certification standards is less noticeable. We further identify notable differences between the digital service and digital manufacturing sectors, thereby enriching our comprehension of the complex relationships between digital innovation, sustainability readiness, and international performance.

Keywords: digital technology innovation; enterprise internationalization performance; sustainability readiness; sustainable technology capabilities; sustainable standards certification

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1. Introduction

The swift advancement of digital technology has dramatically influenced human civilization, altered production relationships, and accelerated the process of enterprise digitalization. Amidst the COVID-19 pandemic, the pace of globalization has decelerated, if not altogether halted. In particular, the recent anti-globalization wave undertaken by some developed countries, mainly manifested in direct technology blockades and limited Entity List and high-tech product export restrictions, has suppressed the international expansion of emerging market economies such as China. Nowadays, countries worldwide strive to seize this new wave of technological revolution and industrial transformation opportunities. Alongside the United Nations' sustainable development goals, the internationalization of enterprises faces numerous emerging challenges.

Firstly, international competition in the digital economy is intensified by exploiting economies of scale and the compounding Matthew effect [1]. Enterprises at the forefront of the digital technology innovation are adopting a "winner-takes-all" approach, while technologically lagging enterprises risk becoming outsiders in the global network [2]. The Global Lighthouse Factory Report, co-published by the World Economic Forum and McKinsey & Company [3], indicates that approximately 70% of enterprises grapple with the dilemmas of the Fourth Industrial Revolution, confronting the "Solow paradox". This paradox represents the predicament of digital enterprises. They must expedite digital technology innovation to secure a foothold in the international market, although this innovation might not necessarily enhance their international performance.

Secondly, technological progression and internationalization may prompt pollution transfer or an excessive utilization of natural resources [4]. Hence, the management of digital technology innovation and internationalization should be aligned with environmental sustainability to effectively advance the global economy. Several countries have established environmental regulations and certification of sustainability standards, making enterprises pursuing internationalization strategies face tighter scrutiny from global stakeholders [5]. Digital enterprises, therefore, must be adequately prepared to integrate environmental sustainability into their digital and internationalization strategies.

Consequently, in the context of sustainable development goals, how does the digital technology innovation of enterprises impact internationalization performance?

To answer this research question, we explored the nonlinear impact of digital technology innovation on firms' international performance and the moderating effect of enterprise sustainability readiness by applying a double fixed effects model to a sample of 269 Chinese listed digital enterprises for the 2012–2019 period. China provides an ideal research laboratory for digitalization, sustainability, and internationalization, offering a wide assortment of data for empirical research. As per the China Academy of Information and Communications Technology, the size of China's digital economy reached CNY 50.2 trillion in 2022, representing a 10.3% annual increase, and leading the world rankings. China has also fostered a cluster of advanced digital enterprises that have set industry benchmarks both domestically and internationally. The World Economic Forum and McKinsey & Company jointly selected the "Lighthouse Factory" that pioneers the Fourth Industrial Revolution. As of January 2023, this list includes 132 enterprises, of which 50 are Chinese enterprises, amounting to 37.9% and claiming the global top spot. From 2012 to 2022, China's share of clean energy consumption rose from 14.5% to 25.5%, while sustaining an annual rate of economic growth of 6.5% with an annual rate of energy consumption growth of 3%. The cumulative decrease in energy consumption intensity reached 26.2%, equivalent to a reduction of 1.4 billion tons of standard coal and a 2.94-billion-ton reduction in carbon dioxide emissions. The former, in terms of per unit of GDP, surpassed China's self-imposed goal. By the end of 2023, China had secured over 75% of international patents in renewable energy technology, leading the world in digitization and sustainable development, thereby providing a roadmap for the development strategy of digitalization, sustainability, and internationalization for global enterprises.

The innovation and contributions of this article are as follows. First, this paper underscores the benefits and costs of digital technology innovation within a unified theoretical framework, shedding light on the nonlinear relationship between digital technology innovation and internationalization performance, and the "digital technology innovation threshold". Second, it highlights the inherent driving factors of sustainable development—the sustainability readiness of enterprises—and its impact on internationalization performance, extending it into two dimensions: sustainable standards certification and sustainable technology capabilities. This approach complements existing research that has solely concentrated on external drivers of sustainable development, e.g., policies, regulations, and pressures from consumers and taxpayers. Third, we merge digitization and sustainability into a single theoretical framework to scrutinize their impact on enterprise internationalization performance, addressing the existing gap. Specifically, we ascertain whether sustainability readiness can enhance or inhibit the effects of digital technology innovation on internationalization performance.

This paper is structured as follows: first, we present a review of the related literature. Then, we analyze the theoretical mechanism between digital technology innovation, sustainability readiness, and internationalization performance and formulate the hypotheses. Next, we detail the research design, empirical contexts, and data analysis. Subsequently, we present the empirical findings. The paper concludes by delineating the implications of our study and proposing future research directions.

2. Literature Review

Digital technology, encompassing artificial intelligence, blockchain, cloud computing, and big data, merges information, computation, communication, and connectivity technologies [6,7]. Although digital technology and internationalization have garnered substantial research attention, no consensus has emerged. Some studies suggest that digital technology can augment an organization's capacity to leverage foreign assets [8], alleviate language barriers [9], and adapt to complex business scenarios [10,11], thereby enhancing its internationalization performance. Conversely, another strand of research posits that digital technology innovation might increase enterprise costs [12]. Moreover, there may be a certain lag between the enterprise's internationalization management capability and digital technology architecture [13], injecting additional risks into the enterprise internationalization efforts. These studies typically neglect to consider the benefits and costs of digital technology innovation within a unified theoretical framework, particularly the nonlinear relationship between digital technology innovation and internationalization performance, as well as the concept of the "digital technology innovation threshold".

Environmental sustainability implies that human welfare must concurrently preserve the resources necessary for human needs and ensure that the waste generated from human activities does not exceed capacity [14]. The influence of sustainability on internationalization performance can either amplify it or inhibit it [15]. While it can help enterprises meet the certification of sustainability standards in their target markets, it might also increase production costs [16]. Nevertheless, most of these studies focus on external factors such as expectations and pressures from competitors, customers, suppliers, and social communities [17,18]. An increasing number of countries are introducing guidelines and regulations forcing enterprises to fulfill their corporate social responsibility during their internationalization endeavors [19]. These studies often overlook whether enterprises are adequately equipped to cope with sustainability pressures such as the impact of enterprise sustainability readiness. The latter refers to "the awareness, skills, and capabilities in applying environmental criteria across the firm's functions and, overall, to the firm's preparedness to implement sustainable business practices" [4] (p. 2). Furthermore, despite the fact that digital development is a critical factor for sustainable development [5], only a few studies have considered sustainability readiness as a situational variable in the framework of studying digitization and internationalization.

As shown in Table 1, few studies discuss internationalization, digitization, and sustainability together, and there is a lack of overall research on listed enterprises. These studies only focus on external drivers of sustainable development, such as policies, regulations, and pressure from consumers and taxpayers. We combine digitization and sustainability into a single theoretical framework to carefully study their impact on the internationalization performance of enterprises and address their existing gaps. Specifically, we determine whether sustainable readiness can enhance or suppress the impact of digital technology innovation on internationalization performance through data from listed enterprises.

Table 1. Documentation of related literature.

Authors	Title	Identified Factors	Research Objects	Research Approaches	Main Findings
[4] Stefano, et al. (2021)	Internationalization, digitalization, and sustainability: Are SMEs ready? A survey on synergies and substituting effects among growth paths	Export intensity, artificial intelligence, and sustainable readiness	13,500 Lombardy's small and medium-sized enterprises	Survey data and empirical study	Digitalization and sustainability are positively related, but they turn to be competing growth paths when the firm internationalizes
[6] Elia, et al. (2020)	Digital entrepreneurship ecosystem: How digital technologies and collective intelligence are reshaping the entrepreneurial process	Digital technologies, collective intelligence, and digital entrepreneurship ecosystem	Nine real enterprises cases—IBM Innovation Jam, Startup Compete, F6S, InnoCentive, iBridge Network, Kickstarter, Uber, Airbnb, and Apple Store	Case study	Technological innovation has a profound impact on entrepreneurship and venture creation
[7] Blichfeldt, et al. (2021)	Performance effects of digital technology adoption and product & service innovation—A process-industry perspective	Digital technology breadth, digital technology depth, innovation, return of sales	747 cases in the process industries from Germany, Austria, Denmark, Switzerland, and the Netherlands	Survey data and empirical study	In low-tech industries, there is an indirect effect of digital technologies on competitive advantage via innovation. In high-tech industries, a direct effect of digital technology adoption on competitive advantage (ROS) is observed
[8] Vadana, et al. (2019)	Digitalization of enterprises in international entrepreneurship and marketing	Mobile technologies, value chain, and international marketing	Five companies—Avito.ru, Farfetch, HelvetiBox, HelloFresh, and IKEA	Case study	This study finds ways to classify the internationalization of companies according to the degree of digitalization of their value chain. The more these companies use internet hardware infrastructure and web and mobile software technologies, the better they can leverage their foreign assets, achieving a higher share of foreign sales with relatively limited foreign assets
[9] Brynjolfsson and Mcafee (2017)	The business of artificial intelligence: What it can—and cannot—do for your organization	Machine learning	Vision systems, speech recognition, and intelligent problem solving	Literature review	AI will not replace managers, but managers who use AI will replace those who do not
[10] Chen, et al. (2019)	The international penetration of business firms: Network effects, liabilities of outsidership and country clout	International penetration, network-based Uppsala model, metwork effects, and country clout	Single dataset for mobile ibusiness platform	Empirical study	Businesses' internationalization process depends critically on users' collective interactions, instead of being solely driven by firms' market commitments, as noted by the Uppsala model. However, businesses may suffer from liabilities of outsidership due to the boundedness of international network effects

Table 1. *Cont.*

Authors	Title	Identified Factors	Research Objects	Research Approaches	Main Findings
[12] Cassetta, et al. (2020)	The relationship between digital technologies and internationalization. Evidence from Italian SMEs	Digital technologies, export, and innovation	2516 active Italian small and medium-sized enterprises	Survey data and empirical study	E-business technologies only have a positive impact on internationalization when they are embedded within process and organizational innovations and investments in digital skills have been made
[15] Cantele and Zardini (2020)	What drives small and medium enterprises towards sustainability? Role of interactions between pressures, barriers, and benefits	Sustainability pressures and perceived benefits	Italian small and medium-sized enterprises	Survey data and empirical study	The results confirmed the hypotheses of a mediated path of influence, thus highlighting the different roles of factors that enable and block sustainability in SMEs
[16] Bag, et al. (2020)	Role of institutional pressures and resources in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities	Institutional pressures, big data, artificial intelligence, and sustainable manufacturing practices	219 companies from the database of the National Association of Automotive Component and Allied Manufacturers and the National Association of Automobile Manufacturers in South Africa	Survey data and empirical study	The paper provides insight regarding the role of institutional pressures on resources and their effects on the adoption of big data analytics-powered artificial intelligence, and how this affects sustainable manufacturing and circular economy capabilities under the moderating effects of organizational flexibility and industry dynamism
[18] Eccles and Klimenko (2019)	A holistic sustainable finance model for the sustainable capital market	Sustainable market capital and sustainable finance model	European sustainable finance policy and methodologies	Literature review	This paper marks three important problems that currently affect the design and implementation of environmental, social, and sustainable policies in the sustainable financial performance of capital markets

3. Theoretical Analysis and Research Hypothesis

3.1. Digital Technology Innovation

Digital technology drives the development of the digital economy. As a general-purpose technology, digital technologies such as blockchain, big data, cloud computing, artificial intelligence, and the Internet of Things continue to integrate with production facilities, terminal equipment, infrastructure and other fields [20], changing the original production mode and consumption mode. Digital technology innovation refers to enterprises, research institutes, and other institutions breaking through the boundaries of existing digital technology theories and applications through self-research, collaborative research and development, and creating new production factors and tools [21]. The innovation and application of digital technology can build a more intuitive and effective social network, sever the plane connection between enterprises in the past, establish an interactive system structure, achieve point-to-point and end-to-end interaction, and greatly improve the overall economic benefits.

3.2. Sustainability Readiness

Sustainable development refers to meeting various current needs as much as possible without compromising the ability of future generations to meet their own needs. In order to achieve sustainable human development, more and more companies are required to implement sustainable practices and processes [22]. This paper follows the approach of Stefano et al. [4] in terms of the awareness, skills, and capabilities in applying environmental criteria across the firm's functions and, overall, to the firm's preparedness to implement sustainable business practices as their sustainability readiness. Enterprises take a series of measures to achieve the goal of improving the environment, enhancing their international green market competitiveness, and achieving sustainable development.

3.3. Enterprise Internationalization Performance

Enterprise internationalization performance is frequently used to measure their overall business performance in overseas markets. Marano [23] believes that there are four types of performance measurement standards at the enterprise level. The first is based on accounting measurement standards, such as return on equity, return on assets, return on sales, return on investment, return on sales, and profit margin. The second type is based on market measurement standards, such as stock market performance, market book value, and excess market value. The third type is sales growth. The fourth type is a survey-based measure to collect respondents' opinions on the company. This paper adopts the third measurement standard—sales growth, while considering the time effect of the data used and the fact that this study focuses on the dynamic relationship between the level of digital technology innovation and the internationalization performance of enterprises.

3.4. Digital Technology Innovation and Enterprise Internationalization Performance

Digital technology can help enterprises to identify customer needs more accurately and quickly from user-generated content, thereby improving customer satisfaction [24]. Machine learning algorithms such as convolutional neural networks exhibit greater competence over traditional statistical methods in decoding complex relationships, managing data, and addressing personalized user needs [25]. This suite of digital technologies facilitates a direct interaction between enterprises and end users, extending the enterprise network beyond traditional business relationships to encompass end users [26]. For instance, transformative technologies such as virtual reality, augmented reality, and 3D printing enable consumers to actively participate in product design and production processes. Enterprises can then adapt their products based on feedback. Users independently finalize product customization in line with their personalized needs through digital interfaces like intelligent terminals and online platforms [27]. The evolution of the digital innovation economy requires an ongoing commitment to enhance and optimize digital technology and methods of knowledge production [28]. Additionally, the reinforcement of innovation element relationships, expansion of innovation subject boundaries, and enhancement of systems and conditions collectively drive system innovation, achieving value creation [29–31].

Digital technology innovation serves as a powerful tool for enterprises to dismantle entry barriers to international markets. Services based on digital technology—offered by manufacturing industry enterprises—are instantly transmitted from producers to consumers, enabling a temporal and spatial separation of service production and consumption, thereby enhancing service tradability [32]. Digital enterprises can permeate foreign markets without a physical presence. This mode of online international expansion augments the probability of digital firms adopting non-equity entry models that leverage their external assets [33]. Digital technology innovation empowers enterprises to transition their global value chains into digitization, intelligence, and disintermediation [34]. Blockchain technology can address the issues of data islands, information asymmetry, and tampering risks encountered by enterprises within the value chain. This provides greater transparency, enabling chain participants to trace information, establish trust mechanisms, improve organizational production, and bolster manufacturing intelligence [35].

However, digital technology innovation can also detrimentally impact the internationalization performance of enterprises and thus should not be overlooked [36,37]. Firstly, there are costs and risks associated with the shift in the company's technological trajectory and product focus. While initial R&D costs and sunk risks related to digital technology and product development are considerable, once the initial investment is absorbed, the marginal cost of large-scale production can be nearly negligible [38]. Therefore, costs and risks will show a trend of first increasing and then decreasing. Moreover, with the strategic focus and resources of the enterprise directed towards digital technology advancements, it can drain resources from overseas market expansion and marketing, potentially leading to a drop in overseas sales of existing product and service lines [39]. Secondly, during the research and implementation of digital technology, aligning and updating production factors can pose challenges. Collaboration between digital technology and other production factors involves time, cost, and fresh capital investment for elements such as digital infrastructure access or the replacement of existing labor with digital resources, particularly the renewal of knowledge elements. Thirdly, due to coordination costs and chain effects related to the digitalization of global production networks, there is a further interdependence between multinational corporations and their ecosystem of partners along with risk chain effects, which spread more rapidly within connected business models [40]. Therefore, multinational corporations are impacted by partner-related risks, such as innovation risks, business risks, and legal risks. External instability caused by natural disasters, power shortages, and social unrest can also make the network structure of multinational corporations vulnerable. Traditional production interruptions can disrupt the availability of a specific location or component, while network disruptions can lead to an overall operational standstill for the enterprise.

Given the above, it is reasonable to assume that digital technology innovation, at a certain level, can decrease costs and increase profits from overseas. The application of digital technology requires a critical mass of users to trigger network effects. Although digital service enterprises' platforms can be accessed globally, their products can only provide value to users when their number in a specific market and interactions reach a critical mass [10,41]. Once a certain user base is achieved, enterprises can utilize big data and algorithms to analyze various consumer behaviors, preferences, functional combinations, price expectations, and market trends to understand global user preferences, utilize user feedback to iteratively update products, and achieve value co-creation with them [19]. The relationship and trust building between digital enterprises and their partners, complementarities, and ecosystems also hinge upon the accumulation of their digital innovation capabilities. Based on these discussions, this study proposes the following hypothesis:

Hypothesis 1 (H1). *The relationship between the digital technology innovation of enterprises and their internationalization performance initially decreases and then increases.*

3.5. Sustainability Readiness and Enterprise Internationalization Performance

3.5.1. Sustainable Standards Certification: An International Green Pass

In response to environmental security concerns and domestic market protection, some developed countries utilize their technological strengths to advocate environmental legislation, create environmental management standards, impose access restrictions on goods, and execute trade restrictions under the pretext of green security. Such measures have culminated in the formation of new green barriers, barring products from developing countries from the global market.

To unify global environmental management standards and address the resulting disputes, the International Organization for Standardization (ISO) has enacted the ISO14000 [42] series of international environmental management standards. Acquiring this certification enables enterprises to transform their competitive advantage from tangible to intangible by gaining stakeholder recognition.

Indeed, ISO14000 certification has emerged as a crucial gateway for overcoming the international green barrier, particularly for entry into European and American markets [43]. The certification helps enterprises establish a green and environmentally friendly image, optimize production processes, and increase product competitiveness, all of which directly enhance brand equity. The certification also equips enterprises with the ability to conserve energy, streamline costs, adhere to government regulations, fulfill social obligations, bolster their public image, and ultimately enhance competitiveness.

With the ISO14000 certification, corporations are linked to an international knowledge institution that advocates for environmental sustainability. This connection facilitates the incorporation of green capabilities into their overall organizational strategy, promoting reconfiguration and enhancing competitiveness [44]. This certification is voluntary and has established a validated framework that multinational corporations can follow to establish effective environmental management systems, enhance employees' environmental protection awareness, and cultivate sustainable development strategic thinking and cultural foundation. In this process, multinational corporations can acquire the latest knowledge and practices to achieve ecological efficiency, improve green products, and establish a foothold in the green market [5]. The following hypothesis is thus proposed:

Hypothesis 2a (H2a). *Sustainable standards certification positively impacts the enterprises' internationalization performance. Certified enterprises display superior internationalization performance.*

3.5.2. Sustainable Technology Capabilities: An Asset and Challenge

Parallel to the shift from high- to low-carbon industries, the embracing of sustainable technology capabilities plays a crucial role in driving sustainable social development. Sustainable technology promotes ecological symbiosis through innovation in production equipment and the genesis of new environmental protection industries and clean production processes [45]. Further, sustainable technology capabilities embed ecological considerations into technological innovation, highlighting efficient resource utilization and pollution reduction [46,47]. The process of producing, applying, and diffusing green knowledge corresponds to a cyclic evolution from "utilization" to "exploration" and back.

However, the system's complexity and the externalities from applying sustainable technology imply that enhanced sustainable technology capabilities might not uniformly improve a company's internationalization performance. While these capabilities can lead to cost reductions and revenue increases by identifying new market opportunities [48], they also require significant investments and may divert resources and attention away from market expansion. Existing research posits that the cost curve for implementing a green strategy follows an inverted U-shaped. Hence, the development of sustainable technology capabilities could initially increase operational burden and negatively impact financial performance. Based on this analysis, this study proposes:

Hypothesis 2b (H2b). *The relationship between the sustainable technology capabilities of enterprises and their internationalization performance is U-shaped; initial enhancement in sustainable technology capabilities leads to a decline in internationalization performance, followed by an increase as these capabilities mature.*

3.6. Moderating Effect of Sustainability Readiness

3.6.1. Theoretical Mechanism of Sustainable Standards Certification

The certification of sustainable standards serves as an enterprise's pledge to integrate sustainability within its core business strategies. This commitment not only solidifies the firm's dedication to global best practices, but also distinguishes them in the increasingly competitive digital landscape [49]. As such, these certifications have the potential to improve a company's competitive standing and influence its international performance. The interplay between digital technology innovation and the certification of sustainable standards may create a U-shaped relationship in determining international performance [4]. Specifically, while digital innovation is instrumental in driving competitive growth, it also requires substantial upfront investments. These initial costs can momentarily dampen international performance.

Nevertheless, the certification of sustainable standards can help mitigate these effects. On the one hand, it conveys the enterprise's commitment to sustainability and corporate responsibility, potentially enhancing its credibility among stakeholders [50]. On the other hand, it may unlock access to new markets and customer bases that value eco-friendly practices, thereby facilitating growth and international expansion [51].

As digital innovation matures, the value of the certification of sustainable standards continues to amplify. By endorsing the firm's commitment to sustainable innovation, it further consolidates the enterprise's reputation and market position. It also ensures the alignment of the firm's digital innovation with sustainability standards, mitigating risks related to regulatory non-compliance. This interplay is expected to alleviate the initial negative impact associated with the costs of digital innovation, reinforcing its positive impact on international performance, which results in the projected U-shaped relationship. Based on these observations, we propose Hypothesis 3a:

Hypothesis 3a (H3a). *The certification of sustainable standards moderately influences the relationship between the digital innovation level and internationalization performance. Through the certification of sustainable standards, the U-shaped relationship between digital technology innovation and enterprise internationalization performance is enhanced.*

3.6.2. Theoretical Mechanism of Sustainable Technology Capabilities

Building on Hypothesis 3a, we further examine how sustainable technology capabilities can moderate the relationship between the digital innovation level and internationalization performance, leading us to Hypothesis 3b.

Sustainable technology capabilities denote an organization's proficiency in devising and implementing technologies that fulfill business goals while minimizing environmental impact and fostering sustainability [24]. In the face of an escalating global demand for sustainable development, these capabilities are becoming crucial [52]. Initially, sustainable technology development may entail high costs with potentially low returns, which can depress international performance. These costs might encompass research and development, technology integration, and human resource development. Moreover, prioritizing sustainability may require resource reallocation, further impacting international performance negatively.

However, as digital innovation progresses, the advantages of sustainable technology capabilities begin to surface. Implementing digital technology promotes sustainability development across different sectors, optimizing energy management, matching supply with demand effectively, and ensuring safety and energy conservation [5]. Digital technologies and algorithms facilitate better and more specialized decision-making processes in environmental management [53,54]. Digitization can facilitate information sharing and contribute to the development of green environmental protection [55–57]. Digital technology sensors can be used to monitor various environmental factors and create a comprehensive environmental regulation model, thus providing accurate and rapid assurance for comprehensive environmental decision making and public services. These capabilities enable firms to create and deploy innovative solutions promoting sustainability across sectors, enhancing efficiency, minimizing waste, and driving cost savings. Additionally, they can lead to the generation of novel, eco-friendly products or services catering to a growing market demand for sustainable solutions.

Therefore, firms with robust sustainable technology capabilities are better equipped to leverage digital innovation for bolstering international performance. They are more adept at navigating the challenges posed by escalating digital innovation and capitalizing on the opportunities it presents. Based on this theoretical understanding, we propose Hypothesis 3b, as follows. Figure 1 depicts the theoretical framework of this paper.

Hypothesis 3b (H3b). *Sustainable technology capabilities have a moderate effect on the relationship between the digital innovation level and internationalization performance. The higher the sustainable technology capabilities of an enterprise, the more pronounced the U-shaped relationship between digital technology innovation and enterprise internationalization performance.*

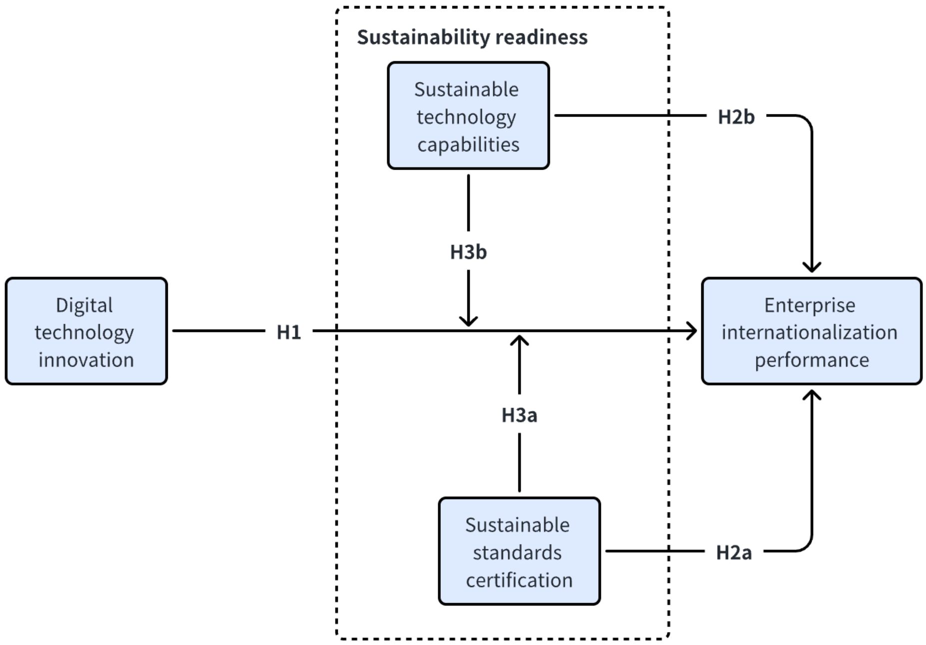

Figure 1. Theoretical framework.

4. Methodology

4.1. Data and Sample

Based on the Statistical Classification of Digital Economy and Its Core Industries (2021) released by the National Bureau of Statistics, we select a sample of enterprises belonging to the core industries of the digital economy. This dataset is selected and matched with the CSMAR Economic and Financial Research Database and Baiteng Network patent data to build the sample for this paper. The 2020 China Digital Economy Industry Panorama Map released by the China Information and Communication Research Institute shows that China's digital economy has entered a mature development stage since 2013. This study selected the period 2012–2019 as the time window, considering the potential lag period for the effectiveness of digital technology, and set the observation starting point to 2012. A sample of listed enterprises belonging to the core industries of the digital economy is screened in the CSMAR database, and the samples of enterprises with SST, ST, and *ST types are excluded. We preliminarily examined 762 listed enterprises. After searching for their digital technology patent information, we selected a sample of 309 enterprises by excluding those enterprises that have been missing digital technology-related patent information for three consecutive years or more. Subsequently, all enterprises with missing data on the adjustment and control variables during the statistical year were excluded, and 269 sample enterprises were ultimately chosen, resulting in 2192 observations over an 8-year period.

4.2. Measurement

The dependent variable: Enterprise internationalization performance (InteP), which is usually measured by overseas sales revenue [8]. We adopt the logarithm of the company's annual overseas sales revenue.

The independent variable: Digital technology innovation (DTI), which is the core explanatory variable of this paper. We grasp the core concept of digital technology innovation and identify highly cited papers and research reports related to digital technology and the Fourth Industrial Revolution. It innovatively constructs the mapping relationship between digital technology and the International Patent Classification (IPC) numbers, so that the level of digital technology innovation and technological characteristics of multinational corporations can be objectively and quantitatively measured, making the data available, comparable, and repeatable. Digital technology is an important component of the Fourth Industrial Revolution paradigm [8]. This paper refers to Ghobakhloo (2018) [58] and the World Economic Forum and summarizes 12 main digital intelligence technology fields. We count the number of digital patents attained by enterprises based on IPC classification numbers. In the basic regression analysis, digital technology innovation lags one year, and in the robustness test, it lags two years. This paper calculates the logarithm of enterprise digital patents as a proxy for the level of digital technology innovation.

Moderator variable: Sustainable readiness. As a moderator, this includes two dimensions—sustainable standard certification and sustainable technology capability—which are measured separately: (1) Sustainable standards certification (ISO), also known as the environmental management standard, is used to search for the corresponding enterprise name through the management system certification results query list website, and to find out whether the enterprise has passed its certification and the year it first passed it, forming green standard data from 2012 to 2019 that can match the chosen sample. In this regression analysis, the green standard lags one year. An ISO value of 1 indicates that the enterprise has passed its environmental management standard certification in that year, while a value of 0 indicates that it has not. (2) Sustainable technology capabilities (Green): The Green Patents Inventory released by the World Intellectual Property Organization provides the IPC code for green patents. According to the green IPC code, we can search the number of green patents by year and region in the patent database of the National Intellectual Property Administration of China. We search for the number of patents corresponding to green IPC codes based on the date of patent authorization. Following Zhu et al. (2019) [59] and Du et al. (2019) [60], the total number of green patents is used as a measure of sustainable technology capabilities, and it is logarithmically processed. In this regression analysis, the sustainable technology capabilities lag by 1 year.

Control variables: Drawing on existing research, we also control characteristic variables at the enterprise level, including ① enterprise age (Age), which is calculated logarithmically by subtracting the registration year from the statistical year; ② enterprise size (Size), measured by the logarithm of the number of employees in the current year; ③ asset liability ratio (ROL), obtained by comparing the total liabilities of a company to its total assets, reflecting the ratio that belongs to liabilities among all assets of the company; ④ marketing expense ratio (SaleR), measured by the proportion of marketing expenses to business revenue; ⑤ R&D expense ratio (RD), which refers to the ratio of R&D expenses to sales revenue; ⑥ management expense ratio (AdmiR), which refers to the ratio of management expenses to business income; and ⑦ China's Digital Institutional Environment

(DigiE), which is an officially calculated digital institutional environment index for the city where the enterprise is registered. This index includes four major indicators: digital industry, digital life, digital culture, and digital government. In addition, it also controls the fixed year effect. Descriptions of variables are shown in Table 2.

Table 2. Description of variables.

Variable Category	Variable Name	Symbols	Measuring Method	Data Sources
Dependent	Enterprise internationalization performance	InteP	InteP = Enterprise's overseas sales revenue	Company annual report
Independent	Digital innovation technology	DTI	DTI = logarithm of the number of core digital technology patents owned by the enterprise in the industry 4.0 field	Baiteng Network
Moderator	Sustainable standards certification	ISO	Certified ISO = 1, not ISO = 0	National Certification and Accreditation Information Public Service Platform
	Sustainable technology capabilities	Green	Green = logarithm of the number of green patents in the International Green List owned by the enterprise	China National Intellectual Property Administration
Controls	Enterprise age	Age	Age = logarithm of statistical year minus enterprise registration year	CSMAR
	Enterprise size	Size	Size = logarithm of the number of employees	CSMAR
	Asset liability ratio	ROL	ROL = total assets/total liabilities	CSMAR
	R&D expense rate	RD	RD = R&D expenses/operating income	CSMAR
	Management fee rate	AdmiR	AdmiR = Management expenses/operating income	CSMAR
	Marketing expense rate	SaleR	SaleR = marketing expenses/operating income	CSMAR
	China's digital institutional environment	DigiE	DigiE = China Municipal Digital System Environment Index	Digital China Index Report

4.3. Model

Considering the current level of digital technology innovation and internationalization performance of Chinese enterprises, this paper refers to Chen (2016) [61] and constructs both a linear model and a quadratic model to examine the functional relationship between the level of digital technology innovation and internationalization performance of Chinese enterprises. Considering the lag in the impact of digital technology innovation and sustainable technology capabilities on the internationalization performance of enterprises, this paper uses indicator data for the internationalization performance of enterprises with a one-year lag. Subsequently, the moderating variables for sustainable standards certification and sustainable technology capabilities, as well as the linear and squared interaction terms with the level of digital technology innovation, were sequentially added to examine their moderating effects.

The regression model specifications are as follows:

A linear model between the level of digital technology innovation and enterprise internationalization performance of:

$$\text{InteP}_{\text{it}} = \beta_0 + \beta_1\text{DTI}_{\text{it}-1} + \beta_K\text{CV}_{\text{it}} + \varepsilon_{\text{it}} \quad (1)$$

The quadratic model of digital technology innovation level and enterprise internationalization performance:

$$\text{InteP}_{\text{it}} = \beta_0 + \beta_1\text{DTI}_{\text{it}-1} + \beta_2\text{DTI}^2_{\text{it}-1} + \beta_K\text{CV}_{\text{it}} + \varepsilon_{\text{it}} \quad (2)$$

The linear model of sustainable standards certification and enterprise internationalization performance:

$$\text{InteP}_{\text{it}} = \beta_0 + \beta_1\text{ISO}_{\text{it}-1} + \beta_K\text{CV}_{\text{it}} + \varepsilon_{\text{it}} \quad (3)$$

The linear model of sustainable technology capabilities and enterprise internationalization performance:

$$\text{InteP}_{\text{it}} = \beta_0 + \beta_1\text{Green}_{\text{it}-1} + \beta_K\text{CV}_{\text{it}} + \varepsilon_{\text{it}} \quad (4)$$

The quadratic model of sustainable technology capabilities and enterprise internationalization performance:

$$\text{InteP}_{\text{it}} = \beta_0 + \beta_1\text{Green}_{\text{it}-1} + \beta_2\text{Green}^2_{\text{it}-1} + \beta_K\text{CV}_{\text{it}} + \varepsilon_{\text{it}} \quad (5)$$

The moderating effect model of sustainable standards certification:

$$\text{InteP}_{\text{it}} = \beta_0 + \beta_1\text{DTI}_{\text{it}-1} + \beta_2\text{DTI}^2_{\text{it}-1} + \beta_3\text{ISO}_{\text{it}-1} + \beta_4\text{ISO}_{\text{it}-1} * \text{DTI}_{\text{it}-1} + \beta_5\text{ISO}_{\text{it}-1} * \text{DTI}^2_{\text{it}-1} + \beta_k\text{CV}_{\text{it}} + \varepsilon_{\text{it}} \quad (6)$$

The moderating effect model of sustainable technology capabilities:

$$\text{InteP}_{\text{it}} = \beta_0 + \beta_1\text{DTI}_{\text{it}-1} + \beta_2\text{DTI}^2_{\text{it}-1} + \beta_3\text{Green}_{\text{it}-1} + \beta_4\text{Green}_{\text{it}-1} * \text{DTI}_{\text{it}-1} + \beta_5\text{Green}_{\text{it}-1} * \text{DTI}^2_{\text{it}-1} + \beta_k\text{CV}_{\text{it}} + \varepsilon_{\text{it}} \quad (7)$$

InteP_{it}—Enterprise internationalization performance of i in year t.

$\text{DTI}_{\text{it}-1}$—Digital technology innovation level of enterprise i in year $t - 1$.

$\text{ISO}_{\text{it}-1}$—Has enterprise i passed the green standard in year t?

$\text{Green}_{\text{it}-1}$—Sustainable technology capabilities of enterprise i in year $t - 1$.

CV_{it}—The control variables for enterprise i in year t include enterprise size (Size), enterprise age (Age), capital-to-liability ratio (ROL), research and development expense ratio (RD), management expense ratio (AdimR), marketing expense ratio (SaleR), and China's digital institutional environment (DigiE).

ε_{it}—Random perturbation term.

This paper distinguishes between fixed effects and random effects in the models by using the Hausman test. The result shows p = 0.0000; thus we adopt a fixed effects model and controls for year effects and individual effects to minimize the heterogeneity between the data. Considering that the data are balanced panel data of large N small T type, there is likely to be heteroscedasticity, so we conducted a heteroscedasticity test, and the results show that the modified Wald statistics of all models are significant at the 1% level, confirming the presence of heteroscedasticity. Hence, the generalized least squares method is required to carry out effective parameter estimation. Finally, considering that the explanatory variables and moderate variables are likely to be highly correlated with their product terms, in order to minimize the impact of multicollinearity, the mean value of the variables related to the interactive terms is centralized, and the variance inflation factors (VIFs) are tested. The VIF values are all less than 2, indicating that the multicollinearity problem of this model does not affect the regression results. The descriptive statistics and correlation analysis are shown in Table 3. The relationship between digital technology innovation levels and internationalization performance presents a notable correlation, with sustainable technology capabilities and sustainable standard certification significantly related to internationalization performance. Regression models will be used for further hypothesis testing.

Table 3. Descriptive statistics and correlation analysis.

Variable	Mean	SD	Max	Min	1	2	3	4	5	6	7	8	9	10	11
1. InteP	20.15	73.69	1167.84	0.0001	1										
2. DTI	2.19	1.49	8.35	0	0.38 ***	1									
3. ISO	0.56	0.50	1	0	0.106 ***	0.129 ***	1								
4. Green	1.80	1.39	6.87	0	0.367 ***	0.548 ***	0.118 ***	1							
5. Size	7.95	1.20	11.46	5.58	0.466 ***	0.482 ***	0.151 ***	0.476 ***	1						
6. Age	2.87	0.28	3.67	1.78	0.140 ***	0.202 ***	0.136 ***	0.091 ***	0.263 ***	1					
7. RD	0.09	0.10	1.37	0.003	−0.093 ***	−0.012	−0.087 ***	−0.088 ***	−0.157 ***	0.012	1				
8. ROL	0.40	0.20	2.86	0.03	0.260 ***	0.265 ***	0.164 ***	0.340 ***	0.506 ***	0.187 ***	−0.209 ***	1			
9. AdmiR	0.13	0.10	1.22	0.009	−0.166 ***	−0.177 ***	−0.254 ***	−0.233 ***	−0.328 ***	−0.194 ***	0.518 ***	−0.342 ***	1		
10. SaleR	0.08	0.06	0.47	0.002	−0.044 *	0.038	−0.147 ***	−0.050 *	−0.141 ***	−0.048 **	0.306 ***	−0.244 ***	0.401 ***	1	
11. DigiE	0.10	0.13	0.62	0.001	0.058 **	0.077 **	0.007	0.018	0.055 **	0.235 ***	0.165 ***	0.059 ***	−0.105 ***	0.107 ***	1

Note: ***, **, and * respectively represent $p < 0.01$, $p < 0.05$, and $p < 0.1$.

5. Results

5.1. Basic Models

Table 3 shows the regression results. Model 1 tests the basic linear model and finds a significant positive linear relationship between digital technology innovation and enterprise internationalization performance at the 10% level. Model 2 incorporates the squared term, forming a nonlinear test model. The squared term of digital technology innovation shows a significant positive correlation with internationalization performance (β = 3.883, $p < 0.01$), while the linear term presents a negative correlation (β = −14.042, $p < 0.01$). The result is shown in Figure 2. This suggests a U-shaped curve relationship between the level of digital technology innovation and internationalization performance, supporting hypothesis 1. As inferred from the U-shaped curve, there is an inflection point in the relationship between digital technology innovation levels and enterprise internationalization performance. When the innovation level is below this point, an increase in innovation corresponds to a decrease in internationalization performance. When the innovation level exceeds the inflection point, the performance improves with the enhancement of digital technology innovation.

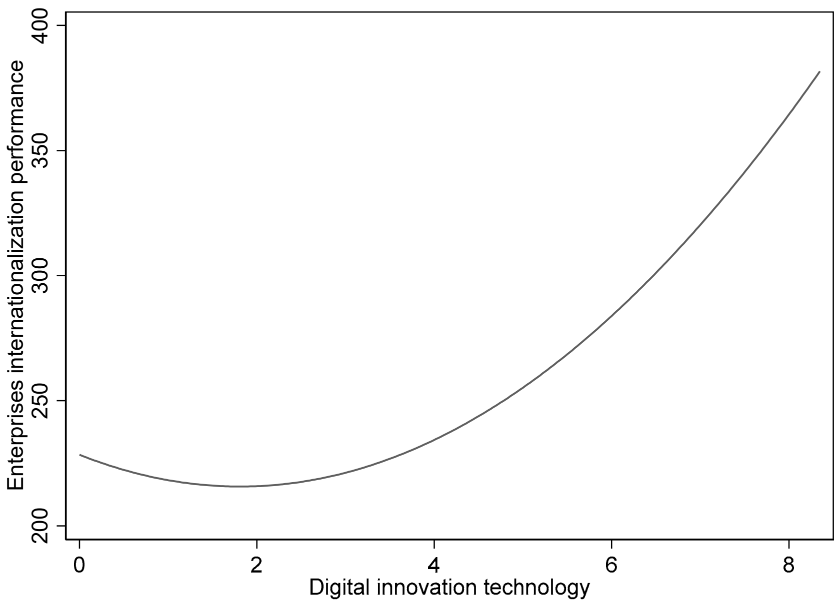

Figure 2. Relationship of digital innovation technology and international performance.

Model 3 suggests that sustainable standards certification has a negligible impact on internationalization performance, not supporting Hypothesis 2a. Model 4 indicates that sustainable technology capabilities positively affect performance (β = 3.404, $p < 0.05$). The results of Model 5 show a U-shaped relationship between sustainable technology capabilities and enterprise internationalization performance, supporting Hypothesis 2b. Similar to the case of digital technology innovation, a turning point exists in the relationship between sustainable technology capabilities and enterprise internationalization performance. Below this point, performance decreases with increasing capabilities; beyond this point, performance improves.

Control variables at the enterprise level show a positive correlation between enterprise size and internationalization performance, and a negative correlation between enterprise age and performance. This aligns with the scale effect advantage in digital technology-related industries. Younger enterprises seem to capitalize better on digital economy opportunities. There is a negative correlation between the ratio of R&D and internationalization performance, implying R&D investment might temporarily hinder internationalization by occupying resources. Regression results of basic relationship are shown in Table 4.

Table 4. Regression results of basic relationship.

Variables	(1)	(2)	(3)	(4)	(5)
DTI	2.112 *	−14.042 ***			
	(1.22)	(2.38)			
DTI^2		3.883 ***			
		(0.49)			
ISO			−5.604		
			(3.75)		
Green				3.404 **	−13.962 ***
				(1.68)	(3.18)
$Green^2$					5.024 ***
					(0.79)
Size	9.937 ***	9.538 ***	9.378 ***	3.048	4.078
	(2.95)	(2.89)	(2.58)	(4.58)	(4.47)
Age	−108.260 ***	−107.566 ***	−98.329 ***	−135.229 ***	−141.320 ***
	(28.16)	(27.52)	(25.07)	(37.05)	(36.18)
RD	−53.207 **	−59.753 **	−42.394 *	−54.337 *	−53.408 *
	(27.47)	(26.86)	(21.59)	(32.01)	(31.25)
ROL	22.571 *	24.379 *	19.448 *	8.765	10.967
	(12.84)	(12.55)	(11.28)	(17.72)	(17.30)
AdmiR	36.808	32.265	38.319 *	75.506 **	69.516 **
	(23.24)	(22.72)	(20.42)	(32.71)	(31.95)
SaleR	3.650	−9.619	1.656	0.553	−8.638
	(36.83)	(36.04)	(33.41)	(56.77)	(55.44)
DigiE	−6.859	−2.133	−4.294	5.450	9.037
	(13.22)	(12.94)	(11.81)	(16.89)	(16.50)
Constant	228.409 ***	227.742 ***	199.080 ***	341.687 ***	357.603 ***
	(76.39)	(76.67)	(67.89)	(98.91)	(96.59)
Firm FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Prob > F	0	0	0	0	0
Prob > chi2	0	0	0	0	0

Note: Robustness standard error is included in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The estimation method is the fixed effects model of the panel data.

5.2. Moderating Effects

The moderating effect of the certification of sustainable standards was examined by adding moderating variables to Models 6 and 7, in conjunction with the interaction terms with linear and squared terms of digital technology innovation. The findings reveal that the coefficients of the moderating variables are negative in both models. Remarkably, in Model 7, the certification of sustainable standards is significantly negatively correlated ($\beta = -7.524$, $p < 0.1$), while the coefficients of the linear and squared interaction terms are both negative, but not statistically significant. This outcome does not endorse Hypotheses 2a and 3a, suggesting instead that the sustainable standards certification negatively influences internationalization performance. Possible explanations include: (1) The high costs associated with implementing environmental management system for the certification of sustainable standards, such as investment in environmental technology, daily environmental management, personnel training, and internal environmental auditing, may deter enterprises from comprehensive implementation [62]. (2) The overwhelming competition often necessitates significant resources, making it challenging for enterprises to truly implement the environmental certification of sustainable management system standards [63]. (3) Enterprises may opt for the certification of sustainable standards instead of a genuine implementation to alleviate external systemic pressure and meet stakeholder expectations [64]. This approach could affect strategic goals and competitive advantages, thereby impacting internationalization performance. (4) While the certification of sustainable standards can enhance enterprises' environmental performance [65], its influence and mechanisms on international performance warrant further study. (5) The green barriers instigated by the certification of sustainable standards primarily impact developed countries. For enterprises targeting developing countries, such certification may be less significant.

Models 8 and 9 investigate the moderating effect of sustainable technology capabilities. In both Models 6 and 8, the first term of the digital technology innovation level is significantly negative, and the second term coefficients are significantly positive. This indicates that the inclusion of sustainable standards certification and sustainable technology capabilities supports Hypothesis 1. In Model 9, the interaction term shows a significant negative correlation with internationalization performance ($\beta = -19.219$, $p < 0.01$), while the quadratic interaction term exhibits a significant positive correlation with international performance ($\beta = 3.909$, $p < 0.01$). These findings indicate that sustainable technology capabilities moderate the relationship between digital innovation level and internationalization performance, reinforcing Hypothesis 3b.

The reinforcing effect of sustainable technology capabilities is reflected in the deepening concavity and leftward shift of the inflection point, as illustrated in Figure 3. A deepening of the concavity prior to the inflection point suggests that a high level of sustainable technology capabilities can initially lead to a significant drop in internationalization performance due to a shift in strategic direction and resource misallocation. However, following the inflection point, high-level sustainable technology capabilities significantly amplify the positive impact of digital technology innovation on enterprise internationalization performance.

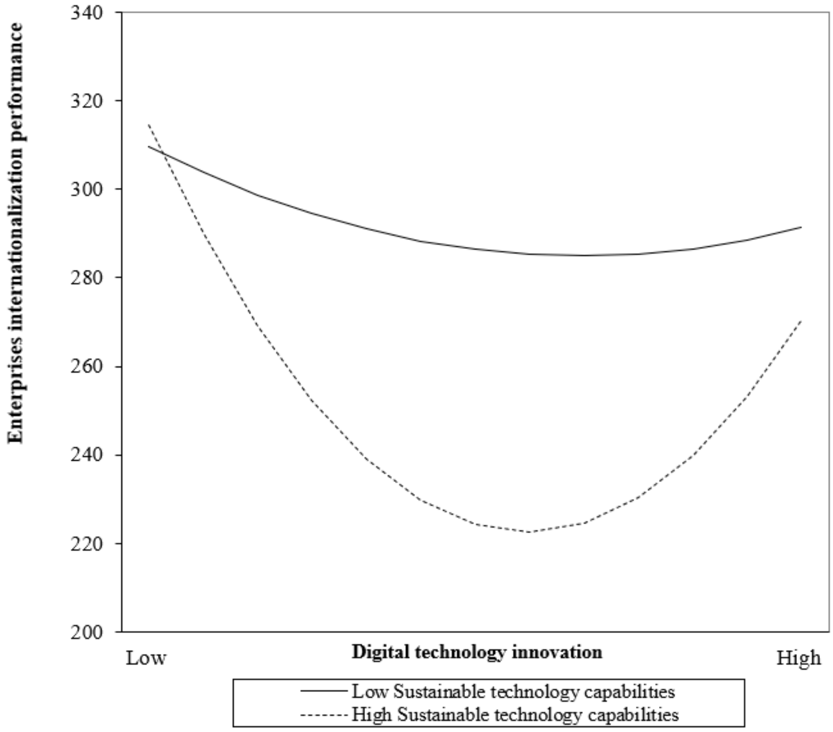

Figure 3. Moderating effect of sustainable technology capabilities.

5.3. Robustness Test

This paper uses two methods to test the robustness of the empirical results. First, considering the sample selection bias, it uses the Heckman two-stage method to verify the sample selection. In the first stage, we use the probit model to calculate the inverse Mills ratio IMR, and add it as a variable to the second-stage model. The results show that its regression coefficient is not significant, which proves that there is no deviation in the selection of samples and that the previous regression results are based on reasonable sample selection. Second, we lagged the independent variable digital technology innovation for two periods, and the regression results are shown in Models 10, 11, 12, and 13 in Table 5.

The regression results of the independent variable data lag two periods are consistent with the regression results of the previous lag one period, which indicates that the research outcomes are both reliable and robust.

Table 5. Regression results of moderate effects.

Variables	(6)	(7)	(8)	(9)
DTI	−13.886 ***	−14.642 ***	−20.527 ***	−8.634 **
	(2.38)	(2.44)	(3.62)	(3.80)
DTI^2	3.875 ***	4.114 ***	5.004 ***	1.234
	(0.49)	(0.53)	(0.67)	(0.77)
ISO	−6.612	−7.524 *		
	(4.26)	(4.31)		
Green			−0.407	1.019
			(1.88)	(1.74)
DTI × ISO		0.178		
		(4.68)		
DTI^2 × ISO		−0.641		
		(1.00)		
DTI × Green				−19.219 ***
				(2.06)
DTI^2 × Green				3.909 ***
				(0.31)
Size	9.515 ***	9.370 ***	4.105	5.771
	(2.89)	(2.89)	(4.83)	(4.33)
Age	−108.314 ***	−108.704 ***	−153.720 ***	−126.061 ***
	(27.51)	(27.51)	(38.35)	(34.48)
RD	−61.049 **	−62.039 **	−130.462 **	−106.314 **
	(26.86)	(26.87)	(55.63)	(49.97)
ROL	25.356 **	25.199 **	9.995	14.990
	(12.56)	(12.57)	(18.89)	(16.95)
AdmiR	34.674	36.633	89.016 **	91.911 ***
	(22.76)	(22.82)	(34.74)	(31.25)
SaleR	−6.734	−8.015	−6.473	−31.769
	(36.07)	(36.08)	(58.51)	(52.55)
DigiE	−0.230	−0.787	13.539	8.976
	(12.99)	(13.00)	(17.57)	(15.78)
Constant	232.550 ***	235.509 ***	405.919 ***	308.436 ***
	(74.68)	(74.71)	(102.46)	(92.24)
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Prob > F	0	0	0	0
Prob > chi2	0	0	0	0

Note: Robustness standard error is included in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The estimation method is the fixed effects model of the panel data.

5.4. Subsample Test: Comparison between Digital Manufacturing and Digital Services

This paper further divides the samples into digital manufacturing industry enterprises and digital service enterprises, and explores whether there is a difference in the impact of digital technology innovation on internationalization performance between digital manufacturing and digital services. The grouped regression results are shown in Table 6. In order to display the results more intuitively, we have plotted scatter plots in Figure 4 for the digital manufacturing enterprises and the digital service enterprises, respectively.

Table 6. Regression results of robustness test.

Variables	(10)	(11)	(12)	(13)
DTI	−14.629 ***		−14.441 ***	−3.342
	(2.63)		(2.72)	(4.12)
DTI^2	4.264 ***		4.242 ***	0.092
	(0.56)		(0.60)	(0.91)
ISO			−6.049	
			(4.84)	
Green		−21.333 ***		2.459
		(3.41)		(1.86)
$Green^2$		7.738 ***		
		(0.86)		
DTI × ISO			−3.081	
			(5.20)	
DTI^2 × ISO			0.447	
			(1.16)	
DTI × green				−18.419 ***
				(2.08)
DTI^2 × green				4.128 ***
				(0.32)
Size	10.864 ***	3.355	10.826 ***	2.289
	(3.38)	(5.20)	(3.38)	(4.91)
Age	−117.021 ***	−143.433 ***	−117.768 ***	−117.526 ***
	(36.80)	(48.51)	(36.83)	(43.93)
RD	−71.397 **	−43.955	−73.502 **	−126.401 ***
	(29.84)	(33.44)	(29.90)	(39.68)
ROL	33.105 **	17.493	33.472 **	25.185
	(14.29)	(20.33)	(14.33)	(18.50)
AdmiR	61.878 **	54.230	65.410 **	143.308 ***
	(27.37)	(36.17)	(27.55)	(41.08)
SaleR	−29.171	20.932	−28.828	−16.631
	(39.79)	(65.23)	(39.87)	(58.06)
DigiE	−9.269	−3.881	−7.982	7.753
	(13.75)	(17.48)	(13.82)	(15.97)
Constant	246.965 **	378.647 ***	251.650 **	309.156 ***
	(101.54)	(133.69)	(101.73)	(119.21)
Observations	1365	880	1365	881
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Prob > F	0	0	0	0
Prob > chi2	0	0	0	0

Note: Robustness standard error is included in parentheses; *** $p < 0.01$, ** $p < 0.05$. The estimation method is the fixed effects model of the panel data.

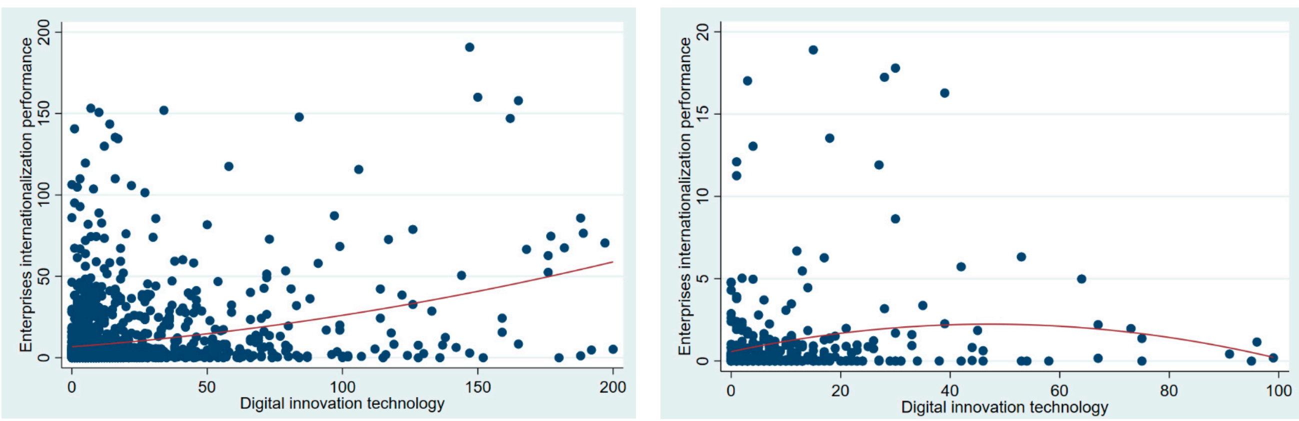

Figure 4. Scatter diagram of digital manufacturing subsample (**left**) and digital service subsample (**right**).

The results show that there is a U-shaped relationship between the level of digital technology innovation and international performance of digital manufacturing industry enterprises, which first decreases and then increases. The certification of sustainable standards still has no significant impact on this U-shaped relationship, while sustainable technology capabilities will strengthen the U-shaped relationship between the level of digital technology innovation and international performance. The finding is consistent with the previous full-sample results.

The regression results of digital service enterprises are different from those of the full-sample quadratic model and the quadratic model of manufacturing industry enterprises. According to Model 18, the linear term of digital technology innovation is significantly positively correlated ($\beta = 3.914$, $p < 0.1$); the squared term is significantly negatively correlated ($\beta = -1.629$, $p < 0.01$). This indicates that for digital service enterprises, the level of digital technology innovation and internationalization performance show an inverted U-shaped relationship of first increasing and then decreasing. Model 21 shows that the coefficients of sustainable technology capabilities and linear and squared interaction terms of digital technology innovation are both positive, but not significant.

In summary, the impact of independent digital technology innovation on the internationalization performance of enterprises in the digital manufacturing and digital service industries shows significant industry heterogeneity. Results of regression test by groups are shown in Table 7.

Table 7. Results of regression test by groups.

	Subsample: Manufacturing Industry Enterprises				**Subsample: Service Industry Enterprises**			
Variables	**(14)**	**(15)**	**(16)**	**(17)**	**(18)**	**(19)**	**(20)**	**(21)**
DTI	−17.522 ***		−18.300 ***	−11.798 ***	3.914 *		6.545 **	19.692 ***
	(2.76)		(2.87)	(4.23)	(2.33)		(2.85)	(5.01)
DTI^2	4.880 ***		5.208 ***	1.999 ***	−1.629 ***		−1.877 ***	−5.541 ***
	(0.57)		(0.62)	(0.86)	(0.49)		(0.52)	(1.00)
ISO			−9.082 *				−3.952	
			(4.89)				(4.95)	
Green		−15.945 ***		1.238		−0.895		0.711
		(3.65)		(1.93)		(3.92)		(2.35)
$Green^2$		5.804 ***				−0.762		
		(0.90)				(1.03)		
DTI × ISO			0.951				17.228 ***	
			(5.55)				(5.47)	
DTI^2 × ISO			−0.931				−4.291 ***	
			(1.19)				(1.04)	
DTI × Green				−20.250 ***				0.808
				(2.26)				(3.77)
DTI^2 × Green				4.108 ***				0.449
				(0.33)				(0.55)
Size	9.931 ***	2.829	9.668 ***	5.652	6.743 **	13.979 *	7.006 **	9.213
	(3.25)	(4.97)	(3.26)	(4.76)	(3.41)	(7.34)	(3.27)	(6.97)
Age	−123.022 ***	−155.696 ***	−124.576 ***	−141.382 ***	10.143	14.874	−5.060	60.842
	(30.92)	(39.65)	(30.92)	(37.12)	(34.47)	(77.75)	(33.28)	(75.45)
RD	−63.888 **	−44.017	−64.637 **	−92.894 **	−20.591	−89.912	−24.891	−36.289
	(31.81)	(35.56)	(31.80)	(56.17)	(25.06)	(65.66)	(24.44)	(63.89)
ROL	29.346 **	11.610	30.246 **	9.954	−18.463	−68.580 **	−21.446	−97.218 ***
	(14.19)	(19.15)	(14.23)	(18.24)	(14.54)	(28.07)	(14.00)	(34.06)
AdmiR	28.272	69.028 *	31.214	83.594 **	19.132	34.568	23.298	−0.202
	(29.43)	(41.31)	(29.43)	(39.70)	(17.95)	(33.01)	(17.72)	(35.94)
SaleR	−8.615	−23.372	−12.123	−30.298	15.460	11.549	15.207	36.964
	(47.87)	(87.86)	(48.03)	(82.49)	(24.84)	(37.87)	(24.29)	(38.91)
DigiE	1.994	13.048	3.431	8.763	−24.612 *	−33.834	−31.673 **	−39.885 **
	(15.19)	(18.73)	(15.26)	(17.62)	(13.02)	(22.20)	(12.84)	(20.57)
Constant	266.896 ***	406.508 ***	277.081 ***	353.413 ***	−72.201	−121.864	−32.987	−220.793
	(83.66)	(105.52)	(83.74)	(99.11)	(95.70)	(204.05)	(92.43)	(199.30)
Company	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Prob > F	0	0	0	0	0	0	0	0
Prob > chi2	0	0	0	0	0	0	0	0

Note: Robustness standard error is included in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The estimation method is the fixed effects model of the panel data.

6. Discussion and Conclusions

Using panel data from Chinese listed enterprises in the core industries of the digital economy from 2012 to 2019, this paper explores the impact of digital technology innovation on the internationalization performance of Chinese digital enterprises, with enterprise sustainability readiness as the moderating variable. It is based on an in-depth analysis of the digital innovation theory and the enterprise internationalization theory, combined with the background offered by the digital economy and the sustainable development goals. The moderating variables are divided into sustainable standards certification and sustainable technology capabilities, and further distinguish the heterogeneity of the above mechanisms in the digital service and digital manufacturing industries.

6.1. Theoretical Implications

Our research findings provide several theoretical implications. First, this paper offers a comprehensive analytical framework that includes both benefits and costs for the debate on whether digital technology is an asset or a burden (e.g., [4,9,13]). Through empirical research on data from Chinese listed enterprises, it provides empirical evidence for the relationship between digital technology and internationalization, revealing a U-shaped relationship between digital technology innovation and internationalization performance. Specifically, the initial innovation achievements are difficult to transform into enterprise competitiveness, but after crossing the "innovation threshold" and reaching a certain scale of digital technology innovation, digital technology innovation improves the internationalization performance of enterprises.

Second, contrary to studies that only focus on external drivers of sustainable development, such as policies, regulations, and institutional pressures (e.g., [16,17,19]), this paper significantly contributes to promoting global sustainable development by providing an empirical framework and path for sustainable development and globalization from a business micro-perspective. In particular, we explored the internal driver of sustainable development, namely, the moderate effect of sustainable readiness on the relationship between digital technology and internationalization performance. Consistent with research findings, e.g. [4], we also found a moderate effect of sustainable readiness. We further divided sustainable readiness into two dimensions: sustainable technology capabilities and sustainable standards certification. We found that the higher the sustainable technology capabilities, the stronger the U-shaped relationship between digital technology innovation and enterprise internationalization performance, while the sustainable standards certification has no significant impact, thereby deepening our understanding of the role of sustainable readiness.

Finally, when developing the theories related to the internationalization of digital enterprises, some studies use digital platforms and digital service enterprises as samples or cases (e.g., [7,11]). Here we found that digital manufacturing industry enterprises and digital service enterprises exhibit a strong industry heterogeneity in the field of empowering international competitiveness with digital technology. Digital manufacturing industry enterprises exhibit a U-shaped relationship, which is consistent with the full sample, while the digital service industry presents an inverted U-shaped structure. It indicates that the theoretical exploration of digital manufacturing enterprises and digital service enterprises need to be conducted separately.

6.2. Practical Implications

This research offers valuable insights into the digitalization, sustainability, and internationalization strategies of firms. Our research findings provide several practical implications for digital enterprises, stakeholders, and policy makers.

First, digital enterprises are encouraged to trigger their innovation ecosystem to swiftly navigate through the internationalization bottlenecks and "innovation inflection points." Businesses should capitalize on the independent and open-source innovation ecosystem fostered by national policies, which align with global trends and China's specific environmental challenges. Large enterprises with a robust manufacturing foundation can establish a "global lighthouse factory" to connect the "end-to-end" value chain, thereby catalyzing a more pronounced Matthew effect in the international market. Small and medium-sized enterprises, in particular, can leverage their funds in digital technology's open-source innovation sphere to swiftly address downturns and reach an innovative turning point that enhances international performance. This progression involves breaking through the supply side technology bottlenecks and the demand side user network bottlenecks. A vital cornerstone for the digital economy's internationalization is the integration of hardware resources and the elevation of software applications within the industrial public intelligent basic service system.

Second, stakeholders in digital industries should foster a shared value ethos promoting a communal future for both the business and the environment, thereby achieving a symbiotic relationship between business performance and social value. Those constrained by limited resources can promote growth by reallocating investments from digitalization towards sustainability. Enterprise managers, shareholders, and suppliers should cooperate to meet the environmental goals by not only focusing on business performance, but also acquiring sustainable standards certification, improving environmental management, and promoting green development industry-wide. Firms engaged in cross-border entrepreneurship in the digital economy domain need to strive to shape a lean internationalization model marked by digital space internationalization and light-asset physical investment, thereby reducing investment risks and circumventing geopolitical barriers.

Third, policy makers are advised to focus on accelerating the construction of national digital infrastructure, such as next-generation supercomputing, cloud computing, artificial intelligence platforms, and broadband networks, to ensure rapid connectivity and data security in the internationalization process of digital enterprises. Governments should also strengthen the development of national innovation systems in the field of digital economy. Furthermore, policies to incentivize the certification and implementation of environmental management systems are needed to compensate for the costs and risks associated with sustainable innovation. The intellectual property rights of businesses' green technology innovation should receive full legal protection, fostering a green technology innovation talent training base and deepening international collaboration in green technology innovation under the "Belt and Road" initiatives.

6.3. Limitations and Directions for Future Research

Although this study contributes to digitalization and internationalization research in a sustainability scenario, it presents some limitations. First, it does not distinguish the internationalization performance of enterprises in developed or developing countries. The market environment and policy requirements of these two groups of countries are vastly different, and future research should differentiate and explore them separately. Second, the conclusions drawn are the result of significant industry heterogeneity. Hence, the moderating effect of sustainability readiness and the impact of digital technology on service industry enterprises needs to be further studied. Third, China is at the forefront of digitization and sustainable development in the world, demonstrating and enlightening the development strategy of digitalization, sustainability, and internationalization for global enterprises. Although China often serves as a representative of emerging market countries, choosing only the Chinese example weakens the generality of the conclusions of this paper due to differences between countries. Future research ought to compare other emerging economies and their national characteristics to examine the pathways suited to improve the international competitiveness of digital enterprise. Finally, this paper potentially assumes that the ultimate goal of all enterprises in digital technology innovation and sustainable development is to improve internationalization performance, which ignores the varying attention paid by different enterprises to their domestic markets. Therefore, future research is encouraged to incorporate the concept of internationalization orientation [34] into the research framework.

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