Mechanism and Empirical Analysis of the Impact of digital technology on Export Product Quality of Chinese Manufacturing Enterprises

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Abstract: We study the impact of digital technology on the export product quality of Chinese manufacturing enterprises using data from China's Customs Database and China's Industrial Enterprise Database from 2000 to 2013. Results demonstrate that digital technology can improve enterprises' export product quality. Digital technology's promotion impacts on export product quality are particularly substantial on export product quality. They are more significant for enterprises in general trade, technology-intensive products, private enterprises, eastern regions, and small and micro enterprises. The mechanism test demonstrates that digital technology impacts the enterprises' export product quality through enterprise costs, productivity, and management effectiveness. Expansion analysis indicates that digital technology can improve multi-product enterprises' export product quality more significantly, increase enterprise export intensive margin, and decrease enterprise export expansive margin.

Keywords: digital technology; export product quality; mechanism analysis; multi-product enterprise; export two-dimensional margin

1. Introduction

China's exports of goods increased from 16.8 billion RMB in 1978 to 641.5 billion RMB in 2022, with an average annual growth rate of 8.63%, demonstrating the nation's leapfrog boom since the reform and opening up.[①] China's early growth in international trade, however, was dependent on its comparative advantage of low factor costs. A crucial concern for China is achieving sustainable development and innovation in trade. The era of information-driven growth has begun due to cross-border innovation and increased expansion in the international digitalization and information sector. The digital economy has become a new engine of economic growth.

The digital economy has become a solid support for the innovative development of China's foreign trade, especially export trade. How to use ICT technology to realize the reduction of export costs and improve export product quality is a new challenge. In this situation, our complete comprehension of the impact of digital technology on global trade and the modernization of Chinese manufacturing firms depends on the research on how digital technology can improve enterprises' export product quality. As the wave of digital technology

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grows, more and more academics are concentrating on the effects of the expansion of the digital economy on exports. Most nations, industries, and business evaluations concur that digital technologies have lowered trade costs, eliminated the old trade distance restrictions, and increased exports. Some academics believe using digital technology to get around geographical restrictions can help exports grow (Elia et al.,2021)[1]. The amount of literature on the quality of export products and the digital economy has gradually grown in recent years. According to a vertically differentiated duopoly model developed by Liu & Serfes (2005)[2], they are applying digital technology's increased information precision results in a monotonic increase in equilibrium profits for high-quality firms and a monotonic decrease in equilibrium profits for low-quality firms. Social and consumer welfare also increases monotonically with the accuracy of information. Using a duopoly model, ShiQiang et al., (2020) [3]created a model of quality disparities. They suggested that an endogenous game of information search costs underlies the discriminatory pricing of product quality by emerging technologies in the digital economy. In terms of empirical data, the studies primarily focus on how digital technology affects productivity and innovation (Pan et al., 2022; Ciarli et al.,2021)[4][5]. According to Yunyan et al., (2022)[6], digital technology can help businesses become more export-resilient. Additionally, foreign capital entrance, the minimum wage, and invention protection can all improve this function (Jinhuan & Lizhen, 2021; Jinhuan & Guanghua, 2021)[7][8]. Information search costs are a significant component of fixed export costs, and digital technology can significantly reduce communication costs between exporters and overseas markets and stimulate exports (Deng et al.,2022)[9]. However, Huang & Song (2019)[10] suggest that Chinese enterprises respond to the digital economy's more competitive market by exporting low-quality products.

The marginal contributions are as follows: (1) To improve the accuracy of the measurement of the level of digital technology, we first calculate the digital technology level at the provincial level using principal component analysis, then at the regional level using the entropy value method, and finally at the enterprise level using the weighting method. (2) In this study, we take enterprise cost, productivity and management efficiency as the influence mechanism of digital technology affecting enterprises' export product quality through mathematical model and theoretical analysis. We enrich the mechanism related to digital technology and exports. (3) We use the within-group difference approach, the heteroskedasticity instrumental variable method, and the instrumental variable method in addition to the endogeneity test. We can solve the endogeneity problem in a variety of more persuasive ways.

2. Materials and methods

2.1 Mathematical model derivation

We will examine the effect and mechanism of digital technology on the quality of an enterprise's export product using Hallak & Sivadasan's (2013)[11] heterogeneous firms' export model. Following the CES utility is the consumer utility function as follows:

$$U_j = \left(\int_{k\in\Omega_j} (\lambda_k q_{jk})^{\frac{\sigma-1}{\sigma}} dk \right)^{\frac{\sigma}{\sigma-1}} \tag{1}$$

Where $k \in \Omega_j$ denotes the types of product consumed by the consumer, λ_k is the quality of product k consumed, q_{jk} is the quantity of product k consumed in nation j, and σ is the elasticity of substitution of the product. We obtain the demand function for product k for consumers in nation j:

$$q_{jk} = \tau_j^{1-\sigma} I_{jk}^{1-\sigma} \lambda_k^{\sigma-1} p_{jk}^{-\sigma} \frac{E_j}{P^{\sigma-1}} \tag{2}$$

Where I_{jk} denotes the information cost of the enterprise when exporting, τ_j denotes the variable cost of the exporting enterprise to ship the product to nation j; p_{jk} denotes the price of product k shipped to nation j; P denotes the price index of all product; and E_j is the total expenditure in nation j. where the market price index is as follows.

$$P = \left(\int_{k \in \Omega_j} \lambda_k^{\ \sigma-1} p_{jk}^{\ 1-\sigma} dk \right)^{\frac{1}{1-\sigma}} \tag{3}$$

Production differences between enterprises depend on enterprise productivity φ and enterprise management efficiency ξ. The marginal cost of an enterprise is as follows.

$$c_k(\lambda_k, \varphi) = \frac{\kappa}{\varphi} \lambda_k^{\ \beta} \tag{4}$$

Where k denotes other factors affecting the enterprise's costs, k > 0; β is the marginal cost elasticity of quality for product k, 0 < k ≤ 1. The enterprise's fixed costs are as follows.

$$\mathrm{F}_k(\lambda_k, \xi) = \mathrm{F}_0 + \frac{f}{\xi} \lambda_k^{\ \alpha} \tag{5}$$

Where F denotes the fixed cost faced by the enterprise in producing product k; f represents the exogenous parameter of the enterprise's production fixed cost, f > 0; α is the quality fixed cost elasticity of product k, and α > 0. The enterprise's profit function is as follows.

$$\pi(q_{jk}, p_{jk}, \lambda_k, I_{jk}) = \tau_j^{1-\sigma} I_{jk}^{1-\sigma} \lambda_k^{\sigma-1} p_{jk}^{-\sigma} \frac{E_j}{P^{\sigma-1}} \left(p_{jk} - \frac{\kappa}{\varphi} \lambda_k^{\beta} \right) - \frac{f}{\xi} \lambda_k^{\ \alpha} - \mathrm{F}_0 - f_x \tag{6}$$

Where f_x denotes the sunk cost paid by the enterprise for exporting, based on the demand and cost functions and profit maximization, we obtain the product quality as follows.

$$\lambda_{jk} = \left[\frac{1-\beta}{\alpha} \tau_j^{1-\sigma} I_{jk}^{1-\sigma} (\frac{\sigma-1}{\sigma})^{\sigma} \left(\frac{\varphi}{\kappa} \right)^{\sigma-1} \frac{\xi}{f} E_j P^{\sigma-1} \right]^{\frac{1}{\alpha-(1-\beta)(\sigma-1)}} \tag{7}$$

Therefore, the channels through which digital technology affects the quality of a company's export product are as follows.

$$\lambda_{jk} = \left[\frac{1-\beta}{\alpha} \tau_j^{1-\sigma} \underbrace{\underbrace{I_{jk}^{1-\sigma}}_{\text{information cost}}}_{\text{transaction level}} (\frac{\sigma-1}{\sigma})^{\sigma} \underbrace{\underbrace{\varphi^{\sigma-1}}_{\text{producticity}} \underbrace{\xi}_{\text{management efficiency}}}_{\text{production level}} \left(\frac{P}{\kappa} \right)^{\sigma-1} \frac{E_j}{f} \right]^{\frac{1}{\alpha-(1-\beta)(\sigma-1)}} \tag{8}$$

According to equation (8), digital technology can affect the enterprise's export product quality by reducing the enterprise's production costs, and improving enterprise productivity and management efficiency.

2.2 Theoretical mechanism analysis and hypothesis

First, digital technology can improve an enterprise's export product quality by reducing production costs. Technological innovation is the key driving force of technological development in endogenous growth theory. Digital technology is a universal platform technology that uses innovation to facilitate the technical development of production processes. Digital technology generally makes it possible to produce and distribute information and innovation more quickly and cheaply. First, digital technology can reduce the transaction costs arising from asymmetric market information. The most crucial feature of ICT technology is to change the information dissemination channels, which can significantly improve information communication efficiency and reduce information costs. Secondly, digital technology has lowered transaction costs (Tu & He, 2023)[12]. Enterprises may interact, transact, and work together directly with suppliers and clients, eliminating intermediaries with digital technology. Instead of offline, customers can use search engines to locate the proper manufacturer online. Extensive data can also make it easier for consumers to compare product costs and purchase more affordable, higher-quality goods; increasing the number of online platforms that offer product and commodity information can decrease the cost of information to find the required goods. Again, digital technology can reduce logistics and distribution costs. Enterprise's export business involves a variety of departments, including procurement, production, transportation, and packaging, and digital technology can integrate information from these departments so that enterprises can better understand their situation, which also involves packaging, transportation, and other multiple lines, and through extensive data analysis, enterprises can choose lower prices and faster delivery.

Hypothesis 1: Digital technology can improve enterprises' export product quality by reducing enterprise production costs.

Second, digital technology can improve the productivity of enterprises to improve export product quality. First, compared to conventional trade, digital technologies increase trade efficiency by reducing trade time and space distances (Yamaka et al., 2023)[13]. The industrialization of digital technology has opened up new market spaces and spawned many new technologies and business models, which in turn has triggered changes in consumer demand. Extensive data analysis technology has increased the effectiveness of information matching and boosted company productivity by reshaping the supply and demand information matching mode at the end of the industrial chain. According to Chen et al.,(2022)[14], the enterprise's quality is closely correlated with how accurately it can obtain information. The development of digital technology has made the acquisition of information more accurate and faster. Technological advancements fuel company productivity, seen when producers pool resources to produce more output. Given the rule of diminishing returns to inputs, enterprise productivity must continuously improve to offset declining returns to input use, for example, technological advancement maintain long-term economic growth (Surya et al., 2021)[15]. Second, the search function of digital technology can develop new customers and markets, expand the market scope of the enterprise, and increase the enterprise's productivity.

Hypothesis 2: Digital technology can improve an enterprise's productivity and thus improve enterprises' export product quality.

Once again, digital technology can improve enterprise management efficiency and thus improve export product quality. First, using digital technology may enhance the effectiveness and optimize the enterprise management process. The digital technology enables enterprises' paperless offices and network offices for businesses, which significantly improves enterprise communication efficiency, addresses the issue of traditional communication's poor effectiveness, and enhances enterprise management effectiveness. Second, the extensive data analysis capability decreases business information asymmetry, optimizes organizational design, and raises management effectiveness (Aben et al., 2021)[16]. As the global economy changes quickly, competition is fiercer, and the market environment is more challenging, enterprises entering the global market will encounter more diversified client groups and more personal customization. Enterprise's management effectiveness is vital for enterprise's survival in export when an enterprise faces competition in the worldwide market. If enterprise's management efficiency is low, it cannot make the right decisions, which may lead to the enterprise withdrawing from the global market. Zhaoling et al., (2020)[17] discovered that increasing an organization's managerial effectiveness can raise the technical complexity of its exports. Tijun et al., (2022)[18] proposed that management efficiency was important for companies to improve export product quality.
Once more, utilizing digital technology can lower an organization's management expenses.
For example, artificial intelligence take place of manual labor, which significantly reduces enterprise's management costs.

Hypothesis 3:Digital technology can improve an enterprise's management efficiency and thus improve export product quality.

3. Empirical framework

3.1 Empirical Specification

We construct the following model to study digital technology's impact on enterprises' export product quality.

$$LnQualtiy_{ft} = \beta_0 + \beta_1 LnDigit_{ft} + \beta_2 \sum LnX + v_c + v_j + v_t + \varepsilon_{cjt} \tag{9}$$

In the models f, j, c, and t denote enterprise, industry, province, and year, respectively, $Quality_{ft}$ denotes enterprise export product quality, and $Digit_{ft}$ is used to measure the level of digital technology at the enterprise level. x denotes the ensemble of control variables, υ_c, υ_j, and υ_t denote province, industry, and year-level fixed effects, respectively, denote ε_{fcjt} random perturbation terms and are clustered at the enterprise level.

3.2 Construction of crucial indicators

3.2.1 Explained variables

The explained variable is the enterprise's export product quality. We refer to Khandelwal et al., (2013)[19] to calculate the enterprise's export product quality. According to the CES utility function, the amount of goods p exported by company f to the nation d in year t:

$$Quantity_{fpdt} = p_{fpdt}^{-\sigma} \lambda_{fpdt}^{\sigma-1} \frac{E_{dt}}{P_{dt}^{1-\sigma}} \tag{10}$$

Formula (11) is created by taking the natural logarithm on both sides of equation (10):

$$\ln Quantity_{fpdt} = \chi_{dt} - \sigma \ln p_{fpdt} + \varepsilon_{fpdt} \tag{11}$$

Where χ_{dt} is a time-destination dummy variable, lnp denotes the price of product p exported by enterprise i to ship destination nation d in year t; ε is the residual term containing quality information. Since product price and product quality affect each other, to overcome endogeneity, we need to choose instrumental variables to carry out and choose the average price of the enterprise's export product p to other countries (except nation m) as an instrumental variable for the price of the export product to nation m. We obtain the export product quality.

$$Quality_{fpdt} = \ln \lambda_{fpdt} = \frac{\hat{\varepsilon}_{fpdt}}{1-\sigma} \tag{12}$$

Next, the quality of the exported product is standardized:

$$Squality_{fpdt} = \frac{quality_{fpdt} - \min quality_{fpdt}}{\max quality_{fpdt} - \min quality_{fpdt}} \tag{13}$$

We weight quality indicators at different levels to obtain the quality of the firm's export products:

$$TQuality = \sum_{\pi} \frac{v_{fpdt}}{\sum_{\pi} v_{fpdt}} \times s\_quality_{fpdt} \tag{14}$$

The v represents the amount of value of the different products.

3.2.2 Core explanatory variables

We are using six indicators from 2000 to 2013, including total revenue from telecommunications services (RMB million), yearly number of cell phone subscribers (million), yearly number of Internet users (million), annual number of information transmission, computer services, and software industry employees (10,000), and total revenue from postal services (RMB million), including Internet broadband access subscribers (thousand). We use principal component analysis combing six indicators into one to measure the level of provincial digital technology development($Lndigit_{ct}$). When an enterprise has a larger share of output in a province, that enterprise is more likely to be affected by the level of digital technology. We use the weight of manufacturing companies' output value in their industries to assess the amount of digital technology at the enterprise level. We get the digitization at the enterprise level:

$$\text{Digit}_{\text{ft}} = \text{LnDigit}_{\text{ct}} * (\text{output}_{\text{ft}}/\text{output}_{\text{cft}}) \tag{15}$$

Where $Lndigit_{ct}$ is the digital technology level of province c in year t, $output_{ft}$ is the sales output of enterprise f in year t, and $output_{cft}$ is the sales output of province c in year t.

3.2.3 Other Variables

The control variables in this paper include the following six. (1) enterprise's age (LnAge): using the difference between the year of the surveyed business and the opening year plus one is taken as a logarithm. (2) Enterprise profitability (Profit): the ratio of operating profit to sales value plus one logarithm. (3) Financing constraint (Finance): the ratio of interest expense to fixed assets plus one is expressed by taking the natural logarithm. The larger the value, the lower the degree of financing constraint. (4) We use Herfindahl Index (HHI) to express the level of competition in the industry. (5) Calculation of industry input tariff (Tariff_Input) and finished goods tariff (Tariff_Output) concerning the method of Amiti et al., (2007)[20]. (6) Foreign investment (LnFDI). We use the logarithm of the amount of foreign capital utilized by Chinese provinces to represent the utilization of foreign capital.

3.3 Data overview

From 2000 to 2013, we matched the China Industrial Enterprise Database and China Customs Database to acquire the export data. Due to numerous missing data factors for industrial businesses in 2010, we removed 2010 data. We first do a data cleaning exercise based on Qiuxian et al., (2024)[21]. We merge the two databases. We match based on the enterprise name and year, then match based on the last seven digits of the enterprise phone number and the enterprise postal code, the merged values of the two matches, and retain the samples of manufacturing enterprises with successful matches by comparing the information from China Industrial Enterprise Database and China Customs Database. We ultimately collect 347530 observations.

4 Estimation results

4.1 Baseline results

We use the stepwise regression approach in this section, Table 1 presents the findings of the benchmark regression of the effect of digital technology on the export product quality of the firms. We do not add control variables in column (1); we add enterprise-level control variables in column (2); we add industry-level control variables in column (3), and (4) province-level control variables are added in the table (1). Results show that the coefficients of the core explanatory variables in columns (1)-(4) are significantly positive, and digital technology can improve an enterprise's export product quality. From the control variables, it is clear that the quality of exports increases with the age and profitability of the enterprise. The coefficient of HHI is small and insignificant, and we can ignore the effect of industry competition on the enterprise's export product quality. The coefficient for input tariffs is significantly positive, suggesting that lower input tariffs can lead to higher-quality export goods. Declining tariffs on intermediate goods allows enterprises to import more high-quality intermediate inputs, and the technological spillover effect of high-quality intermediate inputs can improve the enterprises' export product quality; the coefficient of tariff on finished goods is significantly negative, indicating that the decrease in tariff on finished goods reduces export product quality. Declining tariffs on finished goods have led to more foreign products entering China, leaving

Chinese enterprises at the bottom of the value chain, which is not conducive to innovation and product quality improvement of domestic enterprises; the use of foreign capital at the provincial level reduces enterprise export product quality, and the competitive effect of foreign capital use is higher than the technology spillover effect, which is not conducive to the improvement of enterprise export product quality.

Table 1. Baseline regression results

Variables	(1) LnQuality	(2) LnQuality	(3) LnQuality	(4) LnQuality
LnDigit	0.0042*** (0.0013)	0.0046*** (0.0013)	0.0046*** (0.0013)	0.0045*** (0.0013)
LnAge		0.0135*** (0.0007)	0.0135*** (0.0007)	0.0133*** (0.0007)
Finance		-0.0043*** (0.0010)	-0.0043*** (0.0010)	-0.0044*** (0.0010)
Profit		0.0238*** (0.0020)	0.0238*** (0.0020)	0.0240*** (0.0020)
HHI			-2.09e-06 (6.24e-06)	-2.31e-06 (6.23e-06)
Tariff_output			-0.0131* (0.0067)	-0.0137** (0.0067)
Tariff_input			0.0205 (0.0153)	0.0196 (0.0153)
LnFDI				-0.0006*** (0.0001)
Year Effect	Y	Y	Y	Y
Industry Effect	Y	Y	Y	Y
Province Effect	Y	Y	Y	Y
Observers	345,325	345,325	345,325	345,325
R^2	0.0970	0.1000	0.1000	0.1000

Note: Numbers in parentheses are standard deviations of regression coefficients, and ***, **, and * indicate that the regression results passed the 1%, 5%, and 10% significance tests, respectively. Fixed effects are at the year, industry, and province levels, and standard errors are clustered at the firm level, as shown in the following table.

4.2 Robustness results

4.2.1 Endogeneity

4.2.1.1 Traditional instrumental variable method

Endogeneity problems due to the presence of omitted variables and reciprocal causality, we draw on Qunhui et al.,(2019)[22] approach to the construction of instrumental variables, using the interaction term between the number of post offices per million people and the value added of the information transmission and software industries (time-dependent) in the previous year for each city in 1984 as an instrumental variable for the digital technology level index. We show the regression results in column (1) of Table 2 in agreement with the baseline regression results.

Table 2. Regression results of the endogeneity test

Variables	(1) Traditional tool variable method	(2) Heteroskedasticity instrumental variable method	(3) Intra-group differential method
	LnQuality	LnQuality	△LnQuality
LnDigit	0.0041***	0.0052*	
	(0.0007)	(0.0030)	
△LnDigit			0.0016***
			(4.22e-05)
Control variables	Y	Y	Y
Kleibergen-Paap rk LM	568.360	45.778	
	[0.0000]	[0.0000]	
Kleibergen-Paap rk Ward F	428.562	34.461	
	{16.3800}	{16.3800}	
Observers	313,752	313,752	157,856
R^2	0.2400	0.0320	0.2910

4.2.1.2 Heteroskedasticity instrumental variable method

To further address the endogeneity problem, we use the heteroskedasticity instrumental variables method, drawing on the approach of Huan et al., (2023)[23]; if the residuals of the regression of the endogenous variables on other exogenous variables are heteroscedastic, we use the product of this residual and the decentered exogenous variables as the instrumental variable in a two-stage least squares regression. We show the estimates in the second column of Table 2.

4.2.1.3 Intra-group differential method

The method of in-group difference can eliminate the endogeneity problem caused by missing variables that do not change with time. We differentiate the variables, and then we perform regression. We show the regression results in the third column of Table 2.

4.2.2 Substitution of explained variables

Next, we perform a robustness test. (1) Draw on Broda & Weinstein (2006)[24] to estimate export product quality using the product elasticity of substitution σ on the HS2 digit code to further verify. (2) Export elasticity of substitution equal to 10, remeasuring export product quality. (3) Replacement of export product quality with export product price. (4) Remove outliers at the quality level, and the regression results pass the robustness test.

4.2.3 Substitution of explanatory variables

(1) The six indexes mentioned above were combined into one comprehensive index by entropy method, and the regression results are in column (5) of Table 3. (2) Column (6) of Table 3 uses whether firms use e-mail or the Internet to measure the level of digital technology at the firm level. Results pass the significance test.

Table 3. Regression results of replacement variables

Variables	(1) Lnquality (σ=broda)	(2) Lnquality (σ=10)	(3) Lnp	(4) Remove outliers	(5) Entropy method to calculate the level of digital technology	(6) mailboxes and the Internet to measure the level of digital technology
LnDigit	0.0029*** (0.0005)	0.0502*** (0.0083)	0.2580*** (0.0378)	0.0043*** (0.0012)	0.0079*** (0.0028)	0.0040*** (0.0003)
Control variables	Y	Y	Y	Y	Y	Y
Fixed Effects	Y	Y	Y	Y	Y	Y
Observers	345,325	345,325	345,325	345,325	345,325	159,932
R^2	0.6920	0.2090	0.2590	0.1040	0.1000	0.4850

4.2.4 Other levels of fixed effects

(1) Considering the effect of time-varying industry-level omitted variables on export product quality, we further control for year-industry fixed effects; we show the results in column (1) of Table 4. (2) Considering the impact of industry-level omitted variables on enterprises' export product quality that vary with the province, we further control for industry-province fixed effects, and we show the results in column (2) of Table 4. (3) Further controlling for enterprise fixed effects, we show the results in column (3) of Table 4. Regression results remain robust by transforming fixed effects at different levels.

4.2.5 Heckman two-step method

Since the sample selected in this paper has enterprises with export behavior, we use the Heckman two-step approach to avoid sample selection bias. We estimate the inverse Mills ratio IMR under the total sample using the Probit model. The inverse Mills ratio is brought to the second stage for estimation, and we present the results in column (4) of Table 4. Estimation results show the conclusions remain robust after accounting for sample selectivity bias.

Table 4. Robustness test regression results

Variables	(1) Year-Industry	(2) Industry-Province	(3) Corporate Fixed Effect	(4) Heckman Two-Step Method
LnDigit	0.0053*** (0.0013)	0.0030** (0.0015)	0.0023** (0.0010)	0.0039*** (0.0014)
Imr				0.0041** (0.0019)
Control variables	Y	Y	Y	Y
Year Fixed Effect	N	N	Y	Y
Industry Fixed	N	Y	Y	Y

Effect				
Province Fixed Effect	Y	N	Y	Y
Year-Industry Fixed Effect	Y	N	N	N
Industry-Province Fixed Effect	N	Y	N	N
Corporate Fixed Effect	N	N	Y	N
Observers	345,085	343,108	313,752	103,736
R^2	0.1270	0.1730	0.7970	0.5140

4.2.6 Heterogeneity

4.2.6.1 Trade Mode

According to trade patterns, we classify enterprises into general and processing trade enterprises. Digital technology has a significant positive impact on enterprises' export product quality in both trade modes. The positive promotion effect is more remarkable for enterprises in the "general trade" mode than enterprises in the "processing trade" mode. For general export trade enterprises, the production process is complete, requiring first contact with suppliers, intermediate production, and late transport sales. In contrast, processing trade enterprises are generally "outside the two ends, inside the middle" mode; the enterprise's research and development and sales departments are not carried out in the enterprise. Digital technology for processing trade enterprises boosts the impact of less than general trade enterprises since processing trade enterprises are primarily simple processing, packaging, and other simple mechanical processes.

4.2.6.2 Density of factors

The product was categorized based on factor intensity into labor-intensive, technology-intensive, and capital-intensive products. Results in Table 5 show that digital technology is significantly positive for enterprises' technology-intensive export product quality. Technology-intensive products are knowledge- and technology-intensive industries. ICT technology can quickly integrate capital and technical information, so the positive effect of knowledge-technology spillovers through digital technology is more significant for such products. Labor-intensive products have less technical equipment and more labor quantity needs, labor-intensive products on technology, knowledge requirements are low. Digital technology's knowledge spillover effect has less of an impact on its function. Still, it may result in the market being squeezed out of labor-intensive businesses as technology-intensive businesses grow, which is not suitable for the improvement of its export product quality. Digital technology has little of an influence on capital-intensive companies.

Table 5. Heterogeneity regression results of trade patterns and product factor intensities

Variables	(1)	(2)	(3)	(4)	(5)
	LnQuality	**LnQuality**	**LnQuality**	**LnQuality**	**LnQuality**
	General Trade	**Processing Trade**	**Labor-intensive**	**Capital-intensive**	**Technology-intensive**

LnDigit	0.0032* (0.0018)	0.0116*** (0.0033)	-0.0030** (0.0015)	-0.0009 (0.0019)	0.0042*** (0.0016)
Control variables	Y	Y	Y	Y	Y
Fixed Effect	Y	Y	Y	Y	Y
Observers	97,338	29,774	115,711	78,125	151,480
R^2	0.2890	0.2580	0.4510	0.4410	0.2770

4.2.6.3 Enterprise Ownership

According to ownership, we classify enterprises into state-owned enterprises, private enterprises, and foreign enterprises and carry out regression. Results show that digital technology has a significant positive effect on the export product quality of private enterprises. The larger size of state-owned enterprises and their redundant management structure have a weaker impact on human capital and management technology. Private enterprises are small and easy to turn around, and their spillover effect of applying digital technology is more significant. The spillover effect of digital technology is more effective for private enterprises. The marginal impact of ICT application on information cost reduction and enterprise management improvement is relatively low for foreign enterprises, which have higher information transparency and higher efficiency of enterprise management.

4.2.6.4 Regional Distribution

We classify companies into eastern, central, and western regions based on regional distribution. Results show that the east region is more significantly affected than the central region or the region of the west by the positive influence. The eastern region has the most advanced economy. East region has better policies on various infrastructure and talent introduction. Technology spillover and human capital accumulation effects of digital technology are more robust than enterprises in the central and western regions. The government should encourage the coordinated development of the central and west while balancing the rates of economic development in the east, center, and west.

4.2.6.5 Enterprise size

Depending on the enterprise's size, we divide enterprises into large, medium-sized, and tiny or micro businesses.As shown in Table 6, the positive effect of digital technology is more significant for small and micro-type enterprises than medium and large enterprises. For small and micro-type enterprises, digital technology lowers the export threshold of enterprises, and digital technology's spillover effect is more substantial for small and micro-type enterprises.

Table 6. Heterogeneity regression results

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	LnQuality	LnQuality	LnQuality	LnQuality	LnQuality	LnQuality	LnQuality	LnQuality
	State-owned enterprises	Private enterprises	Foreign-owned enterprises	Eastern Region	Central Region	Western Region	Large and medium-sized enterprises	Micro and Small Enterprises
LnDigit	0.0009 (0.0014)	0.0022** (0.0010)	0.0006 (0.0007)	0.0069* (0.0039)	0.0032*** (0.0005)	0.0060* (0.0036)	0.0017*** (5.37e-05)	0.0029*** (5.33e-05)

Control variables	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Effect	Y	Y	Y	Y	Y	Y	Y	Y
Observers	30,228	132,313	164,278	313,040	21,889	10,218	125,521	165,534
R^2	0.6790	0.7220	0.6870	0.6970	0.6830	0.6830	0.7560	0.7610

5. Mechanism analysis

The following equation base on the mediation model to evaluate the preceding mechanism hypothesis.

$$LnQualtiy_{ft} = \beta_0 + \beta_1 LnDigit_{ft} + \beta_2 \sum LnX + v_c + v_j + v_t + \varepsilon_{cjt} \tag{16}$$

$$M_{ft} = \eta_0 + \eta_1 LnDigit_{ft} + \eta_2 \sum LnX + v_c + v_j + v_t + \varepsilon_{cjt} \tag{17}$$

$$\mathrm{Ln}Quality_{ft} = \theta_0 + \theta_1 LnDigit_{ft} + \theta_2 M_{ft} + \theta_3 \sum LnX + v_c + v_j + v_t + \varepsilon_{cjt} \tag{18}$$

5.1 Enterprise production costs

We divide the enterprise's production costs into variable costs (VC) and fixed costs (FV). The variable cost of an enterprise uses the ratio of the enterprise's main operating cost to the enterprise's primary business sales revenue as a proxy variable. In addition, we refer to the study by Feng et al., (2017)[25], using the enterprise fixed asset to sales ratio as enterprise fixed costs. Results are in columns (1)-(4) of Table 7, which show that digital technology can reduce the variable costs and increase the fixed costs of an enterprise. In columns (2) and (4), the coefficients of variable and fixed costs pass the 1% significance test. Digital technology can improve the export product quality through channels that reduce the company's variable costs while increasing its fixed costs.

5.2 Productivity

We draw on the methodological approach of Olley & Pakes (1992)[26] to calculate enterprise productivity. Regression results are in column (5) of Table 7, which shows that digital technology can improve the enterprise's export product quality. The coefficient of enterprise productivity is significantly positive in column (6) of Table 7, indicating that digital technology can enhance the enterprise's export product quality by boosting enterprise productivity.

5.3 Enterprise management efficiency

Next, we examine the mechanism of enterprise management efficiency, calculated by drawing on Puyang et al., (2018)[27]. ME denotes enterprise management efficiency, whereas a higher ME value indicates a lower enterprise management efficiency. Adding the interaction term between the level of digital technology and enterprise management efficiency to the benchmark regression, we present the regression findings in column (7) of Table 7. The interaction term's coefficient is significantly negative, indicating that the higher the enterprise management efficiency, the stronger the promotion effect of digital technology on enterprises' export product quality.

Table 7. Mechanisms test results

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Corporate Costs				Productivity		ME
	VC	LnQuality	FC	LnQuality	TFP	LnQuality	LnQuality
LnDigit	-0.0942*** (0.0110)	0.0040*** (0.0005)	0.0814*** (0.0167)	0.0040*** (0.0005)	0.0029*** (0.0009)	0.0024*** (0.0006)	0.0028*** (0.0005)
VC		-0.0005*** (0.0001)					
FC				0.0003*** (0.0001)			
TFP						0.0005*** 0.0001	
lnDigit*ME							-0.0002*** (0.0000)
Control variables	Y	Y	Y	Y	Y	Y	Y
Fixed Effect	Y	Y	Y	Y	Y	Y	Y
Observers	223,143	223,143	223,143	223,143	160,755	137,717	204,629
R^2	0.0160	0.7000	0.0770	0.7000	0.2470	0.8810	0.7090

5.4 Further expansion analysis: product diversification and corporate export binary margins

5.4.1 Product Diversification

Currently, multi-product exporters dominate Chinese exporters. We further examine the impact of digital technology on export product quality by multi-product enterprises and single-product enterprises. We classify multi-product and single-product enterprises and consider enterprises exporting less than or equal to 2 types per year as single-product enterprises. To make the results more robust, enterprises that ship less than or equal to 5 kinds of products per year are regarded as single-product enterprises. The results are in Table 8, which shows that digital technology is more effective in improving the quality of products exported by multi-product enterprises.

Table 8. Regression of the impact of digital technology on the quality of single-product and multi-product enterprises

Variables	(1)	(2)	(3)	(4)
	Single product enterprises(product categories≤ 2)	Multi-product enterprises(product categorie＞2)	Single product enterprises(product categories≤ 5)	Multi-product enterprises(product categorie＞5)
	LnQuality	LnQuality	LnQuality	LnQuality
LnDigit	0.0015*** (0.0004)	0.0049*** (0.0004)	0.0021*** (0.0004)	0.0088*** (0.0006)

Control variables	Y	Y	Y	Y
Fixed Effect	Y	Y	Y	Y
Observers	247,174	209,576	238,589	123,383
R^2	0.6530	0.7370	0.7500	0.7510

5.4.2 Export Binary Margin

Enterprises' exports' binary margin measures include extensive and intensive margins in two dimensions: exporting countries and exporting products. We measure extensive margins of enterprises' exports at a national level and product levels. At the national level, they are using the number of nations that the enterprise exports to each year as a proxy variable, and at the product level, using the types of products that the enterprise exports each year as a proxy variable. This paper measures the intensive margins of enterprises' exports at the national level and product level, and this is expressed at the national level by taking the logarithm of the average trade value of enterprises' exports to each nation and at the product level by taking the logarithm of the average export value of each product export. Regression results in Table 9 show that digital technology increases the intensive margin and dampens the expansion margin.

Table 9. Regression results of the binary margins of digital technology on enterprises' exports

Variables	(1)	(2)	(3)	(4)
	Expansion Margin		**Intensive Margin**	
	National Level	**Product Level**	**National Level**	**Product Level**
LnDigit	0.0015***	0.0049***	0.0021***	0.0088***
	(0.0004)	(0.0004)	(0.0004)	(0.0006)
Control variables	Y	Y	Y	Y
Fixed Effect	Y	Y	Y	Y
Observers	247,174	209,576	238,589	123,383
R^2	0.6530	0.7370	0.7500	0.7510

6. Conclusions

Following are our findings: First, digital technology can improve the quality of export products; Second, Digital technology has a more significant impact on enterprises' export product quality in the general trade mode enterprise, technology-intensive product, state-owned enterprises, eastern regions' enterprises and small and micro enterprises; Third, digital technology has an impact on product export quality by increasing fixed costs, decreasing variable costs, and improving company productivity and management efficiency mechanisms; Fourth, Digital technology can improve the quality of export products of multi-product enterprises more obviously and enhance the intense margin of the firm and lower the enterprise's expansion margin.

We make the following recommendations: From the macro perspective, The nation has completed the integration of "Internet+" and the manufacturing industry a long-term strategy, accelerated the construction of China's digital technology infrastructure, increased investment in the digital economy infrastructure, supported R&D in information technology infrastructure, and promoted high-quality development of foreign trade with digital economy; From the meso perspective: China's manufacturing industry is is undergoing a specific period of reform and upgrading. As a result, deepen the application of digital technology in technology-intensive manufacturing, and China's manufacturing sector is being transformed and restructured into technology-intensive enterprises. From the micro level, Guide more small and medium-sized enterprises to use digital technology to enter the global market, introduce advanced management experience and improve the management efficiency of micro-enterprises; enterprises should grasp the development opportunities presented by digital economy platform, use the technology spillover effect of digital technology to enhance the innovation ability of enterprises and improve the quality of their export product.

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