

Digital Technology Innovation and Enterprise Quality Development

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ABSTRACT

Under the background of the digital economy, digital technology innovation has become an important source for enterprises to cultivate new dynamic energy for development, but the relationship between digital technology innovation and high-quality development is still unclear. In this paper, based on the patents in the field of digital technology filed by Chinese listed companies in the manufacturing industry from 2011 to 2021, we use machine learning methods to measure the innovation index of digital technology patents, and then examine the economic impact of digital technology innovation from the perspective of the technological complexity of enterprises' export products. It was found that digital technology innovation can significantly promote the high-quality development of export enterprises, and this conclusion is still valid after the robust type test. In terms of the impact mechanism, digital technological innovation promotes the high-quality development of export enterprises mainly through reducing administrative costs and improving labor efficiency. Further analysis reveals that digital technology innovation has a greater role in fostering larger-scale, non-state-owned, high-tech enterprises. The findings of this paper provide micro-level empirical evidence that digital technology empowers the high-quality development of enterprises, which provides a reference for improving the digitalization of enterprise trade and further promoting the construction of the Digital Strong Trade Project.

KEYWORDS

Digital technology; Export technological sophistication; High-quality development of firms' exports

1. INTRODUCTION

Trade, as the core bridge connecting the domestic and international double cycle, plays a crucial role in today's society. With the rapid development and deep integration of digital technologies such as artificial intelligence, big data, cloud computing, etc., these technologies are continuously penetrating the real economy and becoming the driving force for the structural upgrading of foreign trade and technological innovation. In November 2021, the Ministry of Commerce released the "14th Five-Year Plan for the High-Quality Development of Foreign Trade", which focuses on promoting high-quality development of trade through the implementation of the In November 2021, the Ministry of Commerce released the "14th Five-Year Plan for High-Quality Development of Foreign Trade", which focuses on promoting the high-quality development of trade through the implementation of the "Digital Trade" strategic project, promoting the digitization of the entire trade process and the transformation of the digital field of trade subjects. The report of the 20th Party Congress also pointed out the strategic direction of accelerating the construction of a strong production country, a strong quality country, a strong trade country, and a digital China, emphasizing the development of new-generation information technology, artificial intelligence, and other emerging growth points, and the promotion of the in-depth integration of the real economy with the digital economy. In this context, it is of great practical significance to discuss the improvement of the quality of enterprises' export

products, including their core position in building a trade powerhouse, and how digital technological innovations can effectively promote the sustainable development of enterprises. This discussion is not only of great significance in promoting the high-quality development of trade and the construction of a new development pattern but also plays an important role in promoting the process of Chinese-style modernization.

Enterprise high-quality development refers to the enterprise in the process of operation and development to achieve a high level, high value-added, and high-efficiency economic value, product technology content enhancement is an important feature of the enterprise high-quality development at this stage [1]. Enterprises are not only the micro subject of macroeconomic development, but also the basic organization of meso-industrial reform, so the research on the factors influencing the high-quality development of enterprises has become a subject of increasing concern for scholars. Existing literature has mainly analyzed the influencing factors of high-quality development of enterprises from both external and internal perspectives, and has achieved more comprehensive results. As far as the external influencing factors are concerned, the tax reduction policy [2] and the state-owned assets supervision system [3] can promote the high-quality development of enterprises, and there is a "U" type relationship between the level of regional financial development and the high-quality development of enterprises. In terms of internal factors, improving corporate governance, strengthening digital transformation [6] and technological innovation [5] are conducive to promoting high-quality enterprise development, while manipulating research and development can hinder enterprise development [7].

In the era of the digital economy, digital innovation is a must for enterprises to explore emerging technology fields and accelerate the development and promotion of high-value-added quality products and services, and most of the literature confirms the positive impact of digital construction on enterprise development. First of all, Forman and van Zeebroeck (2012) [8], and Branstetter et al. (2019) [9] pointed out from the perspective of service and product innovation that compared with products and services built on traditional technologies, product and service innovation driven by the use of the Internet and other cutting-edge digital technologies can more effectively promote the improvement of enterprise performance. Second, Brynjolfsson & McElheran (2016), utilizing data from the U.S. manufacturing sector, report that firms that utilize information technology (IT) to manage digital innovation can increase productivity more quickly; Tang Li et al. (2020), utilizing data from the China Enterprise-Lab Matching Survey, find that data management systems have a greater impact on firm performance than the traditional technology-based impact of product and service innovation [11]. Third, He Fan and Liu Hongxia (2019) concluded from the perspective of business model innovation that digital transformation significantly improves the economic efficiency of real enterprises by reducing cost expenditures and improving the efficiency of asset utilization [12]; and Chenyu Zhao (2021) concluded that digital development can improve enterprise performance, create added value, and promote high-quality development of enterprises through service-oriented transformation [13]. Although the exploration of the economic impact of digital innovation at home and abroad has accumulated several valuable research results, a mature theoretical and empirical analysis framework has not yet been established. At present, in an in-depth exploration of how digital technological innovation promotes enterprises to achieve high-quality development, as well as the specific role of the mechanism in this process, the relevant literature is still scarce, pending further comprehensive research and construction.

In addition, some researchers have also explored the impact of digital transformation on firms' exports, such as local researchers Dai Xiang and Ma Haowei (2023), who show that digital transformation overcomes the limitations of consumers' choices of product diversification and provides channels such as the Internet for consumers to learn information about different types of products, which helps firms to timely understand consumers' preferences and market demand, adjust their product mix approach, and improve their export resilience. Pengyang Zhang et al. (2023) argue that digital transformation can improve security through the reconfiguration of firms' supply chains. However,

the literature dealing with the impact of digital technology on firms' high-quality export development is still relatively scarce, and the level of firms' digital technology innovation is still long-term and uncertain.

Drawing on Huang Bo's practice, this paper adopts text analysis to identify digital patents based on the text information of patent application documents of listed companies, and then constructs an index system for assessing the innovation capability of enterprises in digital technology, and uses the export technological complexity of enterprises to portray the level of high-quality development of enterprises, to systematically explore how digital technological innovation can drive the enhancement of the complexity of enterprises' export technology, and analyze the functioning mechanism between them. It is found that digital technological innovation effectively promotes the upgrading of enterprises' export technological complexity by reducing their internal management costs and improving their labor efficiency, and ultimately helps them achieve high-quality development. In further analysis, this paper comprehensively examines the differential impact of the heterogeneity of enterprises' external market environment and internal governance structure on the effectiveness of enterprises' digital technological innovation from the dimensions of differences in enterprise scale, type of ownership, and whether they have the certification of high and new technology enterprises, to provide theoretical basis and practical reference for the formulation of enterprises' targeted development strategies.

The possible marginal contributions of this paper are as follows: first, in terms of exploring the mechanism of action, this paper elucidates the path of digital technological innovation to promote the development of corporate exports to a higher quality by cutting internal management costs and enhancing labor productivity, providing a solid empirical foundation for enterprises to strategically promote the practice of digital technological innovation. Second, in terms of the expansion of research perspectives, given that the current literature mostly focuses on the single dimension of digital technological innovation or enterprise characteristics, this paper takes the lead in integrating the two into a unified analytical framework at the micro level and conducts a comprehensive review and comparison, which is expected to be the first study at home and abroad to systematically assess the impact of digital technological innovation on the technological complexity of Chinese enterprises' exports, and deepen the understanding of the driving factors behind the high-quality development of Chinese enterprises' exports. It deepens the understanding of the driving factors behind the high-quality development of Chinese enterprises' exports. Therefore, based on the digital patent R&D data of listed companies, this paper investigates the relationship between digital technological innovation and the high-quality development of Chinese enterprises' exports, to fill the gaps in existing studies.

2. THEORETICAL ANALYSIS AND RESEARCH HYPOTHESIS

According to Schumpeter's theory of innovation, "innovation", as the fundamental driving force for the continuous evolution and transformation of the economic system, centers on the introduction of an unprecedented "novel combination" of production factors and conditions into the production system. In this perspective, digital innovation plays a crucial role, through the aggregation of user data resources, the integration of cutting-edge knowledge, and the integration of digital components [16], to achieve a significant improvement in the efficiency of data collection and processing, and thus reduce the related costs, for the deep transformation of the economic system to inject new vitality. Digital innovation not only improves the efficiency of information resource utilization, but also deepens the degree of control of the innovation process and the interconnection of operational links, effectively catalyzes the rapid transformation of business models and structural modernization, and ultimately pushes the enterprise towards a higher-quality development track.

First of all, from the perspective of optimal allocation of information resources, the digital technology-enabled "intelligent information infrastructure" can simplify the complexity, refine the vast ocean of data into precise information with transaction value, and accurately match the

enterprise's demand for production factors. Entering the era of the digital economy, the importance of information as a commodity attribute has become more and more significant, and the competitive advantage of economic entities is often rooted in the quality and depth of the information products and services they provide [17]. Digital technological innovation, with its ability to cross geographical and spatial boundaries, realizes the digital mapping of the whole chain of information flow, reconstructs the information dissemination system of the enterprise, ensures the efficient circulation and utilization of information, and can respond quickly to changes in the market and consumer demand [18]. In addition, digital innovation also weakens the negative impact of information asymmetry, cuts down the redundant costs in the search and negotiation process, lays a solid foundation for the pursuit of high-quality development of enterprises, and creates a more transparent and efficient operating environment.

Second, in terms of the controllability of the innovation process, product, marketing, organizational management, and business model innovation driven by digital technology is a key path to promote enterprise cost reduction and high-quality development. First, with the help of digital simulation and its supporting technologies, enterprises can pre-optimize the production process by building virtual scenarios in the product innovation process to reduce certain unnecessary costs [19]; second, improve the level of digital innovation in marketing and organizational management, and accurately locate the market with the help of big data analysis technology to reduce the marketing and management costs [18], and at the same time flexibly cope with the challenges of customers' individualized demand and business refinement management challenges; third, in terms of business model innovation, digital technology optimizes enterprise operation processes through digital expansion and transformation strategies [20], accelerating the pace of enterprise value creation.

Finally, in terms of business process connectivity, digital technology innovation can blur the boundaries between industries, departments, and products [21], promote collaboration and efficient synergy between different subjects, and significantly improve the labor productivity of enterprises. The core advantage of digital technology lies in its powerful connection and integration ability [16], which provides solid support for enterprises to build a digital knowledge network system. Through the combined innovation strategy, potential digital resources are activated to form diversified value creation paths [22], which breaks the shackles of the traditional value creation model, integrates and gives rise to an unprecedentedly large new value chain system, such as the rise of the platform economy and the sharing economy model, which further stimulates the vitality of high-quality business development.

Comprehensive analysis of the above, this paper puts forward the core research hypothesis: digital technological innovation will promote the high-quality development of enterprise exports through the mechanism of reducing management costs and improving labor efficiency.

3. RESEARCH DESIGN

3.1. Data Sources

This paper selects Chinese A-share listed companies in the manufacturing industry from 2011 to 2021 as the research sample. Enterprise export data are from the China Customs Database and China Industrial Enterprises Database. Relevant data on basic corporate information, financial indicators, and corporate governance are from the CSMAR database; data on corporate R&D expenditures are from the CNRDS database; and patent text information of listed companies is from the WinGo financial text data platform. In addition, this paper refers to Huang Bo et al. and treats the initial samples as follows: the samples of ST-type companies are excluded; the samples of companies in the financial industry are excluded; the samples of companies with IPOs of less than one year are excluded; the samples of companies in the information transmission, software, and information technology service industry are excluded; and the samples whose total assets are smaller than total

liabilities are excluded. In addition, to mitigate the effect of extreme values, continuous variables were subjected to a 1% reduction of tails.

3.2. Variable Measurement

3.2.1. Core explanatory variable: digital technology innovation

In this paper, we believe that digital technology innovation patent data can measure the achievements of enterprises in technology innovation activities, in which the strict examination and approval procedures required for invention patent applications make it more reflective of the substantive innovation behavior of enterprises, so we draw on the methods of Huang Bo et al. (2023) and Tao Feng et al. (2023) [23] to identify the digital technology innovation activities of enterprises through the number of listed companies' invention patent applications for digital technology. The specific identification process is as follows: first, through the information of listed companies' invention application patent subdivision classification number provided by China Innovation Patent Research Database (CIRD) and the "Statistical Classification of the Digital Economy and Its Core Industries (2021)" and the "Table of Reference Relationship between the International Patent Classification and the National Economy Industry Classification (2018)" released by the National Bureau of Statistics, the companies belonging to the field of digital technology are identified by comparison. invention application patent code. Second, the number of digital technology invention patent applications filed by enterprises in the current year was summed up, and the digital technology innovation index in the dimension of "enterprise-year" was constructed. Third, the logarithm of the annual digital technology patent application volume of listed companies is added to one as the digital technology innovation indicator.

3.2.2. Explanatory variable: technical complexity of firms' exports

Drawing on Yu Juanjuan and Yu Dongsheng (2018) [24], the income index of Hausmann et al. (2007) is modified by "total factor productivity" to obtain the export technical complexity at the enterprise level. Firstly, according to the research of Hausmann et al. (2007), the formula of export technical complexity at the industry level was obtained:

$$EXI_j = \sum \frac{X_{nj}/X_n}{\sum X_{nj}/X_n} Y_n \quad (1)$$

Where EXI_j is the technological complexity of the industry's exports, X_{nj} denotes the export value of industry j in region n , X_n is the total exports of the region, and Y_n denotes the per capita GDP of country n . The adjustment formula using the total factor productivity of the firm is as follows:

$$EXI_i = \frac{tfp_i}{tfp_j} EXI_j \quad (2)$$

Where tfp_i denotes the total factor productivity of firm i , tfp_j denotes the industry average total factor productivity, and EXI_j is the average export technical complexity of industry j .

3.2.3. Control variables

Referring to previous studies, the following control variables are added to the model: firm age (Age), growth rate (Growth), financial leverage (Leverage), firm size (Size), market value (Tobin), cash flow (Cashflow), and board size (Board). The data of control variables are mainly obtained from China's provincial statistical yearbooks, China's intellectual property statistical yearbooks, and China's urban statistical yearbooks.

3.3. Modeling

Combining the above analysis, the following econometric model is constructed to test the impact of digital transformation on the high-quality development of enterprises' exports:

$$EXI_{i,t} = \beta_0 + \beta_1 Digital_{i,t} + \beta \sum Control + \theta_t + \tau_i + \varepsilon_{i,t} \quad (3)$$

Where subscripts i and t denote firms and years, respectively. The explanatory variable EXI denotes the export technological complexity of firm i ; the core explanatory variable Digital denotes the number of patent applications in the digital economy of the firm; Control is a set of control variables; θ_t , as well as τ_i , denotes the year as well as the firm fixed effects, respectively; and ε is a random perturbation term.

4. ANALYSIS OF EMPIRICAL RESULTS

4.1. Descriptive Statistics

The descriptive statistics of the main variables in this paper are shown in Table 1. The 9514 firm-year observations available after processing contain most of the A-share listed manufacturing companies from 2011-2021. The results show that the mean value of firms' export technical complexity (EXI) in the full sample is 11.16, which is closer to previous literature, and the distribution of the rest of the variables is within a reasonable range.

Table 1. Descriptive statistics of variables

variable	Description of variables	N	Mean	SD	Min	Max
EXI	Calculated from Eqs. (1)(2), the logarithmic representation of the	9,514	11.16	0.480	10.45	13.66
Digital	Number of digital patent applications filed by listed companies during each year, expressed in logarithms	9,514	0.742	1.206	0	5.112
Age	Natural logarithm of the number of years the business has been established	9,514	1.917	0.930	0	3.258
Growth	Annual growth rate of operating income	9,514	0.216	0.476	-0.552	2.964
Leverage	The ratio of total liabilities to total assets	9,514	0.395	0.196	0.0546	0.896
Size	Natural logarithm of the number of employees	9,514	7.686	1.100	5.288	10.80
Tobin	The ratio of total market capitalization to total assets	9,514	0.556	0.167	0.176	0.897
Cashflow	Ratio of net cash flows from operating activities to total assets	9,514	0.149	0.112	0.0118	0.564
Board	Natural logarithm of the number of directors	9,514	2.123	0.186	1.609	2.565

4.2. Benchmark Regression Results

Table 2 presents the results of the benchmark regression on the impact of digital technological innovation on firms' export quality development. The first column considers only the impact of digital

technological innovation on firms' export technological sophistication, controlling for firm and year-fixed effects. The regression results in column (1) show that the coefficient of digital technological innovation is 0.0210, which passes the significance test at the 1% level, suggesting that a rise in the level of digital technological innovation contributes to the technological sophistication of enterprises' exports. The regression results after introducing all control variables are shown in Column (3), and the estimated coefficient of digital technological innovation is significantly positive at the 1% level, which further verifies that there is a significant promotion effect of digital technological innovation on the export technological complexity of enterprises. The previous findings reveal the significant enhancement effect of digital technological innovation on the technological complexity of enterprises' exports, which further validates its positive promotion effect on enterprises' path towards high-quality development. This finding is highly consistent with the theoretical framework and analytical logic previously constructed in this paper, which highlights the important role of digital technological innovation in promoting the high-quality development of enterprises.

Table 2. Benchmark regression test

sports event	(1)	(2)	(3)
Digital	0.0210*** (3.1826)	0.0206*** (3.1217)	0.0195*** (2.9502)
Age	—	0.0352*** (2.8519)	0.0278** (2.1486)
Growth	—	-0.0153* (-1.6978)	-0.0160* (-1.7753)
Leverage	—	0.0014 (0.0358)	-0.0364 (-0.8961)
Size	—	—	0.0271** (2.5210)
Tobin	—	—	0.0777 (1.5417)
Cashflow	—	—	-0.1233** (-2.2312)
Board	—	—	0.0286 (0.7798)
firm fixed effect	yes	yes	yes
Year fixed effect	yes	yes	yes
N	9514	9514	9514
R ²	0.400	0.401	0.401

Note: t-statistics are in parentheses; *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. The regression results of major variables are retained to three decimal places if they are decimals, otherwise they are accurate to three decimal places. The robust standard errors are clustered at the firm level. The table is the same as the table below.

4.3. Mechanism of Action Tests

The results of the current study show that digital technological innovation has a significant positive impact on the quality development of enterprises. According to the previous analysis, the main impact mechanism of digital technology innovation on enterprise quality development includes two possible ways: reducing costs and improving labor efficiency. On the one hand, enhancing digital technology innovation can optimize the management structure and organizational effectiveness of enterprises by the advantages of monitoring, regulation, and automation of digital technology, significantly reducing the operating and management costs, and then improving the overall level of enterprise development

[19]. On the other hand, digital technological innovation effectively breaks through the bottleneck of single-sector value-added, strengthens the interconnectedness of the innovation network [21], promotes the smooth flow of knowledge and cross-sectoral close collaboration, and at the same time, by fully stimulating the innovation potential of the employees, realizes a significant increase in labor productivity, and injects a strong impetus for high-quality development. This paper studies the above mechanism from these two perspectives.

4.3.1. Cost-saving path: digital technology innovation reducing management costs high-quality development

In this paper, we first discuss the specific path for enterprises to effectively cut overhead expenses through the implementation of digital innovation strategies, and then promote their progress towards high-quality development. To deeply analyze this internal mechanism, this paper introduces the management expense ratio (managerial ratio) as a mediating variable, which is specifically defined as the ratio of management expenses to operating income. According to the idea of the three-step method of the mediation effect test, this paper sets up the mediation effect test model (4) and (5) based on the benchmark regression (1):

$$\text{Mediator}_{i,t} = \alpha_0 + \alpha_1 \text{Digital}_{i,t} + \Sigma \text{Controls} + \Sigma \text{Firm} + \Sigma \text{Year} + \varepsilon_{i,t} \quad (4)$$

$$\text{EXI}_{i,t} = \alpha_0 + \alpha_1 \text{Digital}_{i,t} + \alpha_2 \text{Mediator}_{i,t} + \Sigma \text{Controls} + \Sigma \text{Firm} + \Sigma \text{Year} + \varepsilon_{i,t} \quad (5)$$

Where the Mediator is the mediating variable. Model (2) is used to test the effect of Digital on the mediator variable, and model (3) is used to test the mediating effect of the mediator variable in the process of Digital affecting the export technological complexity (EXI) of enterprises.

The results of the analysis of the above model are reported in detail in columns (1)-(3) of Table 3. The results in column (1) indicate that Digital technology innovation (Digitization) exhibits a significant positive impact on the indicator of high-quality development of enterprises (EXI) (estimated coefficient of 0.0195, $p < 0.01$), which highlights its role as the core engine driving the high-quality transformation of the enterprise; the data in column (2) show that Digital innovation (Digital) has a significant inhibitory effect on the administrative expenses (Manageratio) (estimated coefficient of -0.0195, $p < 0.01$); column (2) shows that Digital innovation (Digital) has a significant inhibitory effect on the administrative expenses (Manageratio) (estimated coefficient of 0.0195, $p < 0.01$). (Manageratio) has a significant inhibitory effect (estimated coefficient of -0.0027, $P < 0.01$), validating its ability to effectively cut down the operating costs of enterprises; (3) then, after incorporating Manageratio as a control variable, a significant promotional effect of digital innovation on high-quality development of enterprises is still observed (estimated coefficient of 0.017, $P < 0.05$); and the coefficient of digital innovation (Digital) decreases from 0.0195 to 0.017 at the same level of significance compared with the coefficient in the baseline model, which implies that digital innovation advances the high-quality development of firms by lowering their administrative expenses, and the core hypotheses of this paper are verified.

4.3.2. Labor Efficiency Improvement Path: Digital Innovation Labor Efficiency Improvement High-Quality Development

Subsequently, this paper focuses on exploring the specific path for enterprises to improve employee productivity through digital innovation and thus promote high-quality development. To verify this mechanism, this paper adopts labor productivity (lnLabra) as the mediating variable, specifically defined as the natural logarithm of the ratio of business revenue to the number of employees. The results of the regression analysis on this mechanism are shown in Table 3, columns (1), (4) and (5).

In Column (4), the regression coefficient of digital technology innovation (Digital) on labor productivity (lnLabra) is significantly positive (coefficient of 0.0139, $p < 0.05$), and this result suggests that digital technology innovation has a positive contributing effect on the enhancement of enterprise

labor productivity. Further, the analysis in column (5) reveals that the regression coefficient of labor productivity (lnLabra) on the level of high-quality development of enterprises is positive at 1% significance level, while the regression coefficient of digital innovation (Digital) shrinks to 0.0177 at the same significance level compared with 0.0195 in the baseline model. this change strongly proves that the regression coefficient of labor productivity (lnLabra) on the level of high-quality development of enterprises is positive (with a coefficient of 0.0139, $p < 0.05$). This change strongly proves that labor productivity (lnLabra) plays a mediating role between digital innovation and high-quality development, i.e., digital innovation strengthens the labor efficiency of employees, and then becomes another important driving force to promote enterprises to high-quality development. Accordingly, the core hypothesis of this paper is fully verified and supported.

Table 3. Results of the mediation effect test

Variable	(1)	(2)	(3)	(4)	(5)
	EXI	Manageratio	EXI	lnLabra	EXI
Digital	0.0195*** (2.9502)	-0.0027*** (-3.6139)	0.0170** (2.5581)	0.0139** (2.2289)	0.0177*** (2.7013)
Manageratio			-0.4940*** (-5.4319)		
lnLabra					0.1267*** (10.8596)
control variable	Yes	yes	Yes	yes	Yes
fixed effect	yes	Yes	yes	Yes	Yes
N	9514	9302	9302	9514	9514
R ²	0.401	0.063	0.402	0.241	0.410

4.4. Robustness Check

The previous paper has preliminarily confirmed that digital innovation has a positive contribution to the high-quality development of enterprises. To further consolidate the reliability of this conclusion, this paper adopts a series of rigorous robustness testing measures: first, the robustness of the findings is tested by replacing the metrics of the explanatory variables; second, the selection range of the sample is adjusted to exclude the potential impact of specific samples on the conclusion; and lastly, the sample of the enterprises in municipalities is specifically excluded to further verify the general applicability of the original hypothesis, thus ensuring the comprehensiveness and credibility of the empirical test.

4.4.1. Replacement of digital technology innovation metrics

Patent authorization is more reflective of the real results of enterprise technological innovation than patent application. The number of invention patents granted by enterprises applying individually can more accurately reflect the organizational form of enterprises' innovation activities, therefore, the number of digital technology invention patents granted independently by listed companies is regressed as the core explanatory variable, and the results of Column (2) show that the estimated coefficient of Digital is positive and significant at 1% level, which indicates that the previous results are still robust.

4.4.2. Change the scope of the sample

In the event of a major financial event shock, firms' access to finance, export thresholds, and ease of digital transformation are affected, and ignoring the exploration of these factors may cause endogeneity problems to some extent. Since the sample period of this paper includes a major financial event, the Chinese stock market crash (2015), all samples in 2015 are excluded. The results in column (5) of Table 4 show that the Digital coefficient is still significantly positive at the 1% level after

excluding the shock of exogenous major financial events, and the results of the benchmark regression in this paper are still robust.

4.4.3. Sample of firms excluding municipalities.

Considering that compared with other cities, China's municipalities are usually stronger in terms of economic development and resource agglomeration ability, and the policy support for enterprises is stronger, which may result in bias due to policy support, institutional environment, and resource endowment, this paper deletes the enterprises located in the four municipalities and re-runs the regression test. Column (1) in Table 2 shows the regression results after removing the samples of enterprises in municipalities directly under the central government, and the empirical results show that the test results of the samples of enterprises after removing municipalities directly under the central government still confirm that the improvement of the level of digital technological innovation can significantly promote the enhancement of the technological level of enterprises' exports. The above conclusions are still valid after adding control variables and year and industry fixed effects, which indicates that the results are robust and reliable.

Table 4. Robustness test

sports event	(1)	(2)	(3)
Digital	0.0299*** (3.1740)	0.0216*** (2.9986)	0.0194*** (2.7602)
control variable	Yes	yes	Yes
fixed effect	yes	yes	yes
N	6376	8760	8190
R ²	0.042	0.388	0.401

5. DISCUSSION OF HETEROGENEITY

5.1. Heterogeneity of Enterprise Ownership

Given the inherent differences between state-owned enterprises (SOEs) and private enterprises (POEs) in terms of resource endowment, operational purposes, etc., this paper further subdivided the total sample into two sub-samples of SOEs and POEs within the framework of the baseline model, aiming to explore the potential heterogeneous impacts of digital innovations on the paths of high-quality development of these two types of enterprises. The results of the specific regression analysis are shown in the table. Column (1) shows the regression results for the sub-sample of state-owned enterprises, revealing that the regression coefficient of digital technology innovation (Digital) is 0.151; while column (2), for the sub-sample of non-state-owned enterprises, shows that the regression coefficient of digital technology innovation (Digital) is as high as 0.230, and it is significantly positive at the 1% level. This finding suggests that Digital technological innovation is more effective in promoting high-quality development of enterprises in non-state-owned enterprises compared to state-owned enterprises, thus validating the difference in the impact of Digital technological innovation on enterprises with different ownership.

5.2. Heterogeneity in Firm Size

Based on the total asset size of enterprises, this paper subdivided the total sample into two sub-samples of large-scale enterprise group and small-scale enterprise group, aiming at exploring in-depth how the difference in enterprise size affects the promotion effect of digital innovation on the high-quality development of enterprises. The results of the specific regression analysis are displayed in Table Column (3) and Column (4). Column (3) shows the regression results of large-scale enterprises, and the regression coefficient of digital innovation on enterprise high-quality development is 0.0245 (P<0.01); column (4) shows the regression results of small-scale enterprises, and the regression

coefficient of digital innovation is 0.0153, which suggests that digital innovation has a stronger role in promoting the high-quality development of large-scale enterprises compared with that of small-scale enterprises. development is stronger.

5.3. Heterogeneity of High-Tech Enterprise Qualifications

The qualification of high-tech enterprises may have an impact on the correlation between digital technological innovation and export technological complexity. First of all, high-tech enterprises, due to their profound human capital reserves and technological accumulation, lay a solid foundation for the realization and application of digital technological innovations, thus accelerating the practical process of technological innovation. In addition, the qualification of such enterprises is often accompanied by multiple favorable policies such as tax breaks and financial subsidies, which effectively alleviate the cost pressure of enterprises in the process of digital technology R&D and innovation, and encourage them to achieve higher economic returns through technological innovation paths, and indirectly promote the significant increase in the technological complexity of export products. To verify the above hypotheses, this paper carries out a careful grouping analysis of the research samples based on whether the sample enterprises have obtained the qualification of high-tech enterprise certification. The data in columns (5) and (6) in Table 5 show that among the high-tech enterprise group, digital technological innovation promotes the technical complexity of exports more prominently, which is in line with the previous theoretical speculation.

Table 5. Heterogeneity Impact Analysis

	(1)		(2)		(3)	
	state enterprise	non-state enterprise	oldest	few	Yes	No
Digital	0.0151 (1.3616)	0.0230*** (2.8368)	0.0245*** (2.9283)	0.0153 (1.3431)	0.0211*** (2.8610)	0.0060* (1.9607)
control variable	yes	yes	yes	yes	yes	yes
fixed effect	yes	yes	yes	yes	yes	yes
N	2562	6935	4757	4757	8054	1460
R ²	0.484	0.353	0.399	0.303	0.396	0.960

6. CONCLUSIONS AND INSIGHTS

Digital technology has emerged as a key catalyst for building a strong trading nation, playing an increasingly important role in improving trade efficiency, restructuring trade processes, cutting trade costs, and enhancing trade quality. This study focuses on a sample of Chinese A-share listed manufacturing companies from 2011 to 2021, uses the status of digital patent applications as an indicator system to measure the innovation capacity of digital technology, and then analyzes how this innovation capacity affects the process of high-quality development of enterprises' exports. The results of the study show that digital technology innovation has a significant positive effect on the overall export growth and quality improvement of enterprises. This finding remains solid and reliable after several rounds of robustness tests. Further exploration of the mechanism reveals that digital technology innovation effectively promotes the high-quality development of firms' exports mainly through the two paths of cutting internal management costs and improving labor productivity. In addition, compared with state-owned enterprises (SOEs), private firms show stronger motivation in promoting high-quality development through digital innovation; at the level of firm size, digital innovation of large firms contributes more significantly to the high-quality development of large firms than that of small firms; and, compared with non-high-tech firms, high-tech firms have a more

pronounced positive effect on the high-quality development of high-tech firms through digital innovation.

The research results of this paper can provide some policy recommendations for enhancing the core competitiveness of China's foreign trade in the context of the new development model. First, enhancing support for enterprises' digital transformation and technological innovation aims to shape Chinese enterprises' unique competitive advantages in the wave of digital economy. China's 14th Five-Year Plan explicitly proposes to "strengthen the application of key innovations in digital technology." This strategic orientation echoes our research findings that digital technology innovation not only deepens the complexity of firms' export technologies, but also paves a solid path for high-quality development. China has a "mega-scale" advantage in the development of the digital economy (Development Research Center of the State Council et al., 2020), and in recent years, the scale of the digital economy has been expanding rapidly, and many enterprises are accelerating into the fast lane of digital transformation. However, due to the many challenges facing digital technology innovation, coupled with the traditional Chinese concept of seeking stability (Qu et al., 2022), some enterprises are still hesitant to embark on the digital innovation journey on their own. Therefore, the government should formulate a series of scientific and efficient incentives for digital innovation, inject the necessary financial incentives through tax breaks and state funding, and accurately guide the convergence of state resources and market capital to the field of digital innovation, to stimulate the enthusiasm of enterprises for R&D and innovation, and promote their continuous accumulation of digital innovation results, which will ultimately empower Chinese enterprises to realize a higher quality development leap.

Second, it focuses on the specific application scenarios of digital technology innovation in enterprise practice and the optimization of its required internal environment, aiming at accurately docking and promoting the process of deep integration between digital technology and the real economy. The report of the 20th Party Congress points out that it is necessary to "accelerate the development of the digital economy, promote the deep integration of the digital economy and the real economy, and create internationally competitive digital industry clusters". This study provides an in-depth analysis of how digital technological innovation specifically works on the internal mechanism of the complexity of enterprise export technology, and answers the question of how enterprises can benefit from digital technological innovation (Teece, 2018), which not only helps to distill successful cases of digital technology assisting in the transformation and upgrading of the real economy, but also provides solid theoretical support for the promotion of the integration of the two. Enterprises should actively self-assess the urgent needs of their digital transformation, the actual benefits of technological innovation, and the general trend of the industry's digital evolution, based on which they can accurately locate and select appropriate digital application scenarios, to more accurately and efficiently utilize digital technological innovation to drive their progress towards high-quality development. At the same time, enterprises also need to deeply analyze the internal environment and clarify the basic conditions for the implementation of digital technological innovation. To ensure that both technology-intensive and labor-intensive enterprises can stand out and gain a competitive advantage in digital transformation, enterprises should further enhance their understanding of the value of digital technology innovation, actively grasp the valuable opportunities closely linked to business restructuring and modernization, and proactively embrace change to achieve sustainable development.

Thirdly, optimize the operating environment of enterprises and strengthen the effectiveness of human capital and the driving force of independent innovation. The first strategy is to take advantage of the Internet platform, proactively integrate into the enterprise information ecosystem, eliminate information barriers, and realize the seamless connection and sharing of information in various links; relying on data analysis, anticipate market changes, and flexibly adjust the strategy, to effectively cut transaction costs. Secondly, we are committed to the continuous optimization of the employee skills system, increasing the proportion of senior employees in the team, accelerating the accumulation and

upgrading of human capital, and thus enhancing the competitiveness and overall quality of talents in the manufacturing industry. Furthermore, it focuses on breaking through key technological bottlenecks, stimulating the innovation potential of the Internet of Things, artificial intelligence, and other cutting-edge technologies, deepening the mode of cooperation between the industry, academia, research, and application, strengthening the mechanism of collaborative innovation, and promoting the fundamental transformation of enterprises from follower-type innovation to leading-type independent innovation.

This paper systematically researches the impact and mechanism of digital technological innovation on promoting the development of export quality of enterprises from the perspective of the technological complexity of enterprises' exports, but there are still some shortcomings due to the limitation of space. First of all, export quality development is a new development concept with multiple connotations such as global competitiveness, improving export quality and resisting external risks. Future research can also examine the overall impact of digital transformation on the export quality development of enterprises from the perspectives of export strength, export product categories, export duration and export volatility. Secondly, this paper mainly investigates the promotion effect of digital technology innovation on the development of enterprise export quality, and future research can also examine the influencing factors of trade quality development from the perspectives of cognitive ability of enterprise leaders, border export access system and so on. Finally, this paper selects listed companies as research samples, and in the future, small and medium-sized micro-enterprises, professional enterprises and specific emerging enterprises can also be selected as research samples for more in-depth analysis.

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