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Digital Transformation and Export Quality of Chinese Products: An Analysis Based on Innovation Efficiency and Total Factor Productivity

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Abstract: In recent years, Chinese manufacturing enterprises compete to chase the wave of "digital revolution", digital empowerment has become an important strategic path of technological reform for many manufacturing enterprises. Based on the micro data of listed companies, this paper investigates the impact of digital transformation of Chinese listed companies on the quality of their export products. It is found that digital transformation can significantly improve the quality of enterprises' export products. After a series of robustness tests, this conclusion is still valid, and there are two ways to improve innovation performance and total factor productivity. The export product quality enhancement effect of enterprise digital transformation also has the heterogeneity of ownership, region and industry. In the further study, this paper also examines the impact of digital transformation on the internal salary gap of enterprises, and finds that digital transformation may increase the internal salary gap of enterprises, and form a "masking effect" on the quality of export products. To a certain extent, this paper deepens the understanding of the study of enterprise digital transformation on the quality of export products and its differences, and provides certain guidance for enterprises to implement the strategy of digital transformation.

Keywords: digital transformation; innovation performance; total factor productivity; quality improvement

1. Introduction

Since its accession to the WTO, China's foreign trade has achieved leapfrog development. Through processing trade, China has participated in the global industrial division of labor and promoted the initial development of manufacturing industry. However, in recent years, China's labor cost has risen, traditional labor comparative advantages have weakened, internal and external environment is complicated and severe, external demand is depressed, and trade frictions are frequent. As a result, the long-term explosive growth rate of foreign trade volume has slowed down, and the competition among products in the international product market has shifted from price competition to quality competition. The quality upgrade of export products is a key link for Chinese manufacturing industries to maintain their competitiveness in international markets.

To be specific, information technology has crossed all fields in the world, improved the operation efficiency of the industry and built a new digital economy system. The digital economy has added new drivers to world economic growth and brought about profound changes in international trade. In 2021, the value added of digital economy in 47 major countries reached US $38.1 trillion, a nominal increase of 15.6 percent year on year, accounting for 45.0 percent of GDP. The development of digital economy provides the shortest and fastest way for all countries, especially developing countries, to realize the modernization of industrial information (AHMEDOV, 2020) [1], promoting China's Internet to enter a new stage from the consumer Internet to the industrial Internet, and manufacturing enterprises are starting digital transformation one after another. It is urgent to improve the high-quality development of foreign trade. Digital empowerment is conducive to

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promoting the digital transformation of China's manufacturing enterprises, so as to achieve high-quality development of trade and become an important opportunity to enhance international competitiveness. In addition, foreign trade manufacturing enterprises are micro subjects to promote digital transformation. Under the new situation of accelerating the promotion of digital enabling manufacturing industry, how to effectively release the effect of enterprise digital transformation on the quality improvement of export products has become an important issue concerned by Chinese enterprises in recent years.

2. Literature Review

From the existing literature, there are several types of researches closely related to the problems in this paper.

First of all, related research on export product quality measurement. With the development of Melitz (2003) [2] New trade theory, export enterprises propose that only enterprises with high production efficiency will export due to their high production efficiency and low production cost, and the quality of export products has become an important issue in the field of international trade research. Hallak and Sivadasan (2009) [3] found that the price of export products is higher than that of non-export enterprises, because the quality of products of export enterprises is higher than that of non-export enterprises. The heterogeneity of enterprises includes not only the differences in production efficiency, but also the differences in the quality of export products. The product quality level is a latent variable that is difficult to estimate. Domestic and foreign scholars estimate the quality level of export products mainly through product technical complexity and product use value. Schott (2008) [4] proposed to measure the export technology maturity (complexity) by using the relative price data of China's export products. It also points out that the improvement of product quality is an important reason for the rise of Chinese exports. Hallak J C. (2008) [5], Feenstra and Romalis (2014) [6], Manova and Zhang (2012) [7], etc., all use market performance to reverse infer product quality and replace quality through unit value. Secondly, aiming at value, another important content of export product quality, Khandelwal (2010) [8] introduced consumer utility function into the model derivation process and proposed the idea of using utility mean to measure product quality level. In addition, scholars believe that the weighted per capita GDP of each country can also be used to represent the level of technological complexity of export products. Finally, in the relevant research on how to improve the quality of export products, from the perspective of policy environment, Amiti and Khan delwal (2013) [9] pointed out that low tariff is conducive to the catch-up of higher-quality products with the world's advanced level, but will hinder the upgrading of lower-quality products. Bas and Strauss Kahn (2014) [10] found that the reduction of import input tariffs can promote enterprises to use higher quality inputs, thus improving the quality and price of export products.

Secondly, research on the definition and measurement of digital transformation. Mesenbourg(2001) [11] defines the category of digital economy, including digital hardware and software infrastructure, digital business network and organization, and products traded in e-commerce, laying the foundation for measuring enterprises' digital transformation. In the relevant researches on Digitization, digitization conversion, Digitalization and Digial transformation are three different development stages (see Figure 1). Digital transformation emphasizes the core competitiveness of enterprises in the business environment market through the development of new business. Bharadwaj (2013) [12] et al. believe that digital transformation will make use of digital resources to generate differentiated value, promote the exchange and communication between enterprises, so as to promote manufacturing enterprises to improve and create production processes and products, and enhance their technological innovation performance. DeStefano and Timmis (2021) [13] used the density of industrial robots to measure the indicators of different digital technologies, and discussed in depth the influence and mechanism of digital empowerment on the quality of export products. Loughran and McDonald (2014) [14] measured the digital transformation of enterprises by word frequency statistics through annual reports of listed companies in different years.

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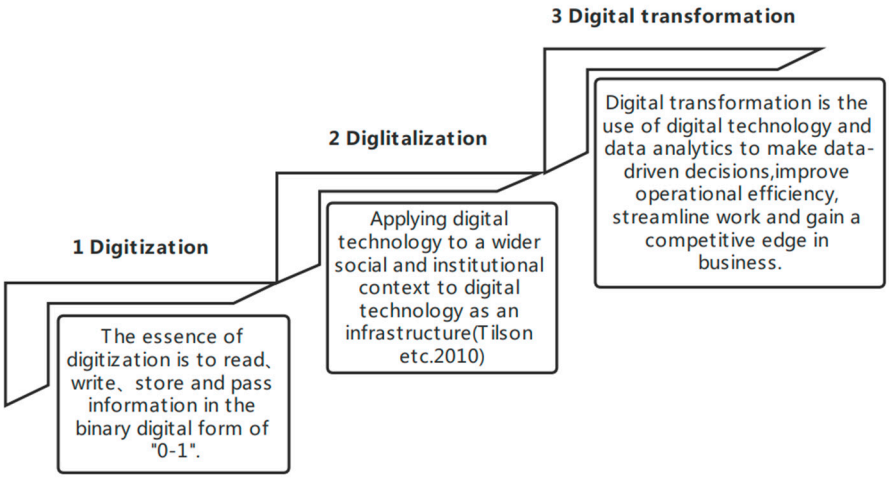

Figure 1. Digital transformation and development stage.

Finally, the study on the influence of enterprise digital transformation on enterprise foreign trade behavior. In the era of digital economy, the Internet has been integrated into every aspect of enterprise production and life. Abouzeedan et al. (2013) [15] believes that enterprise Internetization is an innovation in organization and management, and its essence is a specific form of service-oriented investment, including improving the ability of enterprises to acquire resources needed for operation, production, innovation and other activities and the ability to save relevant expenses. Nwankpa et al. (2016) [16] found that enterprise IT capability is an important part of digital transformation, and further improve the quality of enterprise products, so as to enhance international competitiveness. Goldfarb and Tucker (2019) [17] believe that the Internet and other digital technologies can reduce the cost in five aspects, namely, search cost, replication cost, transportation cost, tracking cost and verification cost. Among them, The reduction of search cost can improve the efficiency of information matching and the efficiency of information communication and organization. Lendle and Olarreaga, et al. (2018) [18], reduce the information cost and search cost of enterprises in international trade. Olarreaga M (2016) [19]. Thus, the quality of enterprises' export products can be improved (DeStefano and Timmis, 2021) [13].

Combing through the existing literature, it is found that there are many studies on the measurement of export product quality and enterprise digital transformation, and most of them believe that digital technology can significantly improve enterprises' trade mode and enhance the quality of export products. However, on the whole, there are the following deficiencies: For the first time, Khandelwal (2010) [20] is generally adopted to measure the quality of export products, but the results vary greatly and may be negative, which cannot truly reflect the quality level of enterprise products. Secondly, in the measurement of enterprise digital transformation, management decision-making is an important factor affecting enterprise digital transformation, but the current digital transformation indicators rarely consider management decision-making factors. Finally, the existing literature has carried out a theoretical review of the export product quality effect of enterprise digital transformation, but there is a lack of empirical discussion on the mechanism verification and analysis. The marginal contribution of this paper lies in the following aspects: In terms of method measurement, this paper calculates the export product quality results at the enterprise-product level by using standardization and weighting methods, so as to eliminate the problem of large difference in export product quality results. In terms of the measurement of digital transformation, this paper adopts text analysis method to extract the relevant statements of digital transformation in the "management Discussion and analysis (MD&A) part" in the annual report, so as to investigate the digital transformation of enterprises. From the perspective of enterprises, this paper discusses the influence mechanism of digital transformation on the quality of enterprises' export products, and considers the mechanism of innovation performance and total factor productivity, which provides scientific support for in-depth discussion on the path of digital transformation to promote the quality

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of enterprises' export products. Further analysis, this paper also found that the digital transformation of enterprises through the internal salary gap on the quality of export products to cover the effect, broaden the enterprise digital transformation of export product quality improvement effect, explore the internal mechanism of the internal salary gap in digital transformation on the quality of export products.

3. Theoretical Mechanism Analysis

The improvement of export product quality needs to be realized through the increase of technical complexity and the improvement of product use value. The characteristics of digital technology, such as information transmission across time and space, data creation, sharing and helping to reduce transaction costs, enable enterprises to realize the transformation of production mode with the help of digital technology. This paper mainly studies the effect of innovation performance and total factor productivity on the quality improvement of export products in digital transformation.

3.1. Innovation Performance

Innovation performance refers to the substantial number of innovations that an enterprise makes to improve production efficiency and increase the number of invention patent applications by applying new technologies to production activities. Ahuja and Katila (2001) [21] **believe** that the number of patent applications is a good indicator to measure innovation performance. This is different from the index of innovation ability that includes both the number of invention patent applications and the number of non-invention patents. The world has entered a dual-drive era in which "innovation" and "data" are driven together. At the macro level, digital technology, with its extensive permeability, data-driven, system intelligence and other features, reduces R&D costs and improves R&D efficiency, providing more possibilities and development space for export enterprises to carry out innovation research and development and the evolution of innovation mode, and indirectly providing the necessary knowledge driven and efficiency improvement basis for upgrading the quality of export products. At the intermediate level, reusability and replicability of data information promote data elements to be transformed into new knowledge for unlimited reuse among export enterprises in the industry. The open source and non-competitive characteristics of digital technology determine its extensive diffusion and knowledge spillover effect. Gema Albort-Morant et al. (2018) [22] pointed out in their study that innovative organizations can internalize relevant technical knowledge into new products, services or processes by absorbing capacity, thus promoting green innovation performance. Therefore, the development of digital economy provides a broader platform and element support for the innovative development of export industry. At the micro level, digital technology reduces the information asymmetry of the global market, and a fairer international market competition environment makes continuous innovation become the main way for export enterprises to maintain their market position. Meanwhile, digital technology brings new business forms and models such as big data, artificial intelligence and blockchain. The large-scale application of digital technology provides accurate insight into the mass personalized consumption demand. The research and development design of enterprises can more accurately grasp the latest consumption preferences of the international market, greatly improve the innovation performance, optimize the enterprise's research and development mode, create a broader space and platform for enterprise innovation, promote the improvement of enterprise innovation performance through digital transformation, and indirectly promote the quality upgrade of export products. Accordingly, this paper proposes:

Hypothesis 1: Digital transformation can indirectly promote the quality improvement of export products by improving the innovation performance of enterprises.

3.2. Total Factor Productivity

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Total factor productivity refers to the systematic productivity of an enterprise. The improvement of total factor productivity is the development of industrial upgrading and productivity, including the role of technological progress, as well as business model innovation, organizational reform and management mode reform. Firm productivity has an important relationship with the development of international trade. According to Melitz (2003) [2] 's heterogeneous firm trade theory, the impact of firm productivity on export is that only enterprises with higher production efficiency can explore the international market due to higher export costs than domestic trade. Digital transformation improves total factor productivity by improving enterprise production efficiency, promoting technological progress and realizing scale effect, thus promoting enterprise export. Meanwhile, free trade reallocates resources from low-productivity enterprises and low-yield products to high-productivity and high-yield products. Under the influence of the externality effect of digital economy, The fierce competition in the international market will also promote the digital transformation of enterprises and further improve the productivity of enterprises. First of all, digital transformation can save production cost and improve production efficiency by accelerating automation and intelligence of production process, intelligent control and precise management. The improvement of enterprise productivity represents the improvement of enterprise technical level. The digital transformation of production process and the application of intelligent production control system can reduce production loss, improve manufacturing process level, promote manufacturing technology progress, and directly affect the quality of export products. Secondly, in the process of digital transformation, when an enterprise introduces digital technology, it will also train employees and hire high-tech talents to meet the needs of digital operation of the enterprise, and highly skilled employees will further improve the production and management level of the enterprise, so as to improve product quality. Finally, the digital transformation of enterprises can innovate production technology at a lower marginal cost, laying the foundation for expanding the scale of manufacturing enterprises. The external effect of digital technology makes enterprises usually choose partners to establish alliances to obtain innovation resources, thus forming the scale effect of the region where the enterprises are located. Improve the total factor productivity of enterprises through its own scale effect and regional scale effect. It can be seen that digital technology can promote the improvement of total factor productivity in various ways, thus promoting the upgrading of product quality. Accordingly, this paper proposes:

Hypothesis 2: Digital transformation can indirectly promote the quality improvement of export products by improving total factor productivity.

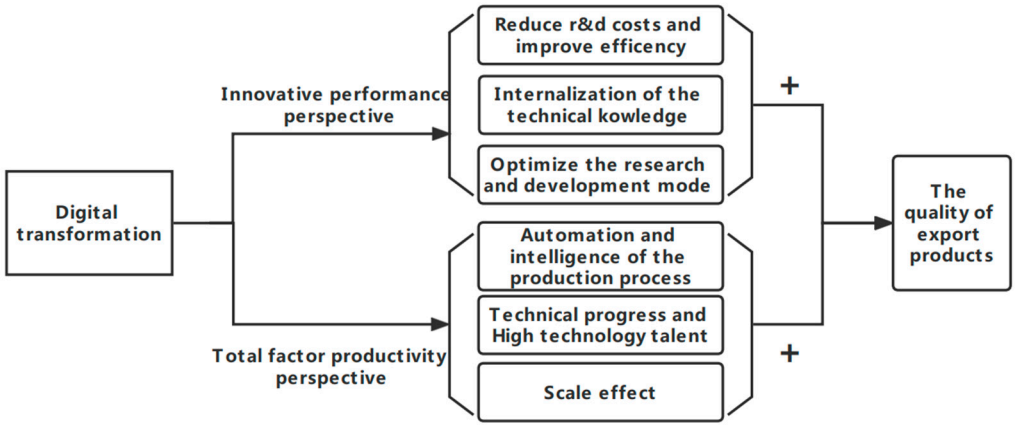

Figure 2. The influence mechanism of digital transformation on the quality of export products.

4. Research Design

4.1. Model Setting

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Step 1: This paper first verifies the impact of enterprise digital transformation on the quality of export products, so the model of this paper is set as follows:

$$quality_{ijct} = \alpha_0 + \alpha_1 dig_{it} + vX_{it} + \delta_i + \delta_j + \delta_p + \delta_t + \varepsilon_{ijt} \quad (1)$$

In Formula (1), represents the quality of products exported by the enterprise to the country in the year, represents the degree of digital transformation of the enterprise in the year, represents the combination of a series of control variables, and respectively represents the fixed effects of the enterprise, product, province and city and year, represents the random disturbance term. Let's focus on the coefficient.

Step 2: Considering the possible mediating mechanism of enterprise digital transformation on export product quality, according to Propositions (1) and (2), we respectively take enterprise innovation performance and enterprise total factor productivity as mediating variables to test the mediating mechanism. The mediation model is as follows:

$$innov_{ijt} = \beta_0 + \beta_1 dig_{it} + vX_{it} + \delta_i + \delta_j + \delta_p + \delta_t + \varepsilon_{ijt} \quad (2)$$

$$tfp_{ijt} = \gamma_0 + \gamma_1 dig_{it} + vX_{it} + \delta_i + \delta_j + \delta_p + \delta_t + \varepsilon_{ijt} \quad (3)$$

The above Equations (2) and (3) mainly focus on coefficient$\beta_1$andγ_1, and other variables in the model are consistent with (1), so it will not be repeated here.

4.2. Sample Selection and Data Sources

According to the availability of data, this paper takes the database of China Customs enterprises from 2007 to 2015 and China A-share listed companies as the initial samples, and matches customs enterprises with A-share listed companies to form the data of customs listed companies, and carries out the following data screening: (1) ST and ST* enterprises are excluded during the sample investigation; (2) Enterprises whose age is negative during the sample period are excluded. (3) Samples of enterprises with asset-liability ratio greater than 100% are excluded. The data is mainly divided into two parts: the Gutai 'an Database (CSMAR) and the China Customs Enterprise Database. Specific variables are described as follows:

Step1: For the explained variables, the demand information prediction method of Khandelwal et al. (2013) [23] and Fan et al. (2015) [24] are used for reference to calculate the export product quality of the 6-digit code (HS6) of customs products. First, construct the regression equation of export product price to export product quality:

$$lnq_{ijct} + \sigma dig_{ijct} = \kappa_i + \kappa_{ct} + \nu_{ijct} \quad (4)$$

Step2: In the above equation (4), represents elasticity of product substitution, represents the difference between groups of different customs products, and controls the fixed effect at the country-year level. The symbols of other variables are consistent with the previous expressions, so we will not repeat them here. The elasticity of product substitution is generally provided by Broda et al. (2006) [25] to provide the elasticity value of HS2-bit codes. The residual term is obtained by regression of the above Equation (4), from which the quality of export products at the level of enterprise-product-exporter-year can be obtained:

$$q_{ijct} = \frac{\nu_{ijct}}{\sigma - 1} \quad (5)$$

Step3: Considering the problem that the quality of export products obtained by calculation cannot be compared between different industries of the same enterprise, the quality of export products obtained is standardized:

$$qsd_{ijct} = \frac{q_{ijct} - minq_{ijct}}{maxq_{ijct} - minq_{ijct}} \quad (6)$$

Step4: Take the ratio of export quantity to the total export of the enterprise as weight, and finally get the quality of export products at the enterprise level:

$$quality_{ijct} = \sum_{j \in \Omega} \frac{quantity_{ijct}}{\sum_c quantity_{ijct}} \times qsd_{ijct} \quad (7)$$

In Formula (7), represents the product set and represents the quantity of products exported by the enterprise to the country in the year. Other variables are consistent with the previous statements, so we will not repeat them here.

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As for the core explanatory variable Digital Transformation Index (dig), firstly, 30 important digital economy policy documents released by the Central People's Government and the Ministry of Industry and Information Technology were collected, and a digital dictionary was constructed to obtain 238 digital keywords. Secondly, Python software is used to analyze the text of the annual reports of listed companies, extract the "management discussion and analysis (MD&A) part", and calculate the number of digital keywords appearing in MD&A of each company every year. Finally, the number of occurrences of each key word in MD&A is added up, and the total number of occurrences of digital key words obtained is divided by the length of MD&A segment to obtain the annual digitalization degree index of each enterprise. The larger the index value, the higher the degree of digital transformation.

As for the intermediary variables, innovation performance (innov) and total factor productivity (tfp) are selected as the intermediary variables of enterprise digital transformation and export product quality according to the hypothesis above. Among them, according to Pasquali (2006) [26], innovation performance may sometimes be a strategic behavior to obtain innovation subsidies. Therefore, the quality of invention patent, utility model patent and design patent is different. Therefore, the weights of the applied invention patents, utility model patents and design patents were added together and logarithm was taken as the measurement index of innovation output. The weights of the three kinds of patents were marked with the value of 3:2:1. Second, innovation input is measured by the ratio of R&D expenditure to operating income. Finally, innovation output is divided by innovation input to get innovation performance. For total factor productivity, LP method proposed by Levinsohn and Petrin et al. (2003) [27] is adopted, because LP method can effectively solve the problem of sample loss.

For control variables, the following control variables are selected in the basic line of previous literature on the quality of export products of enterprises: (1) Enterprise size (size), logarithm of total enterprise assets; (2) The age of the enterprise, the difference between the year of the current year and the year of the establishment of the enterprise is added by 1, and then the logarithm is taken; (3) Return on equity (roe), net profit divided by the average balance of shareholders' equity; (4) Total assets turnover (ato), operating income divided by average total assets; (5) cashflow ratio, net cashflow from operating activities divided by total assets; (6) Asset-liability ratio (lev), total liabilities divided by total assets at the end of the year; (7) Tobin's q (tq), the market value of outstanding shares plus the product of the number of non-tradable shares and the net asset value per share plus the book value of liabilities to the total value divided by the total assets; (8) Herfindahl Index (hhi), using the Herfindahl index to calculate the industry monopoly index of enterprises, the calculation formula is $hhi=\sum_{i=1}^{n}(total\_sale_{ij}) / \sum_{i=1}^{n} total\_sale_{ij})^2$.Where, $total\_sale_{ij}$ represents the main business income of enterprises in the industry. Table 1 below reports descriptive statistics of the above variables.

Table 1. Descriptive statistics.

Variable Type	Variable	Variable name	Sample size	Mean	Standard Deviation	Minimum	Maximum
Explained variable	quality	quality of export products	410325	0.0325	0.1180	0.0000	1.0000
Core explanatory variable	dig	digital transformation	410325	0.0059	0.0063	0.0000	0.0521
Mediating variable	innov	innovation efficiency	346326	0.2237	0.0903	0.0000	0.4315
	tfp	total factor productivity	410325	8.5174	1.1587	5.2837	11.6660
Control variable	size	enterprise scale	410325	22.3726	1.5302	17.8787	27.7033
	age	enterprise age	410325	0.9459	0.1754	0.0940	1.3589
	roe	net assets income rate	410325	0.0998	0.1331	-2.2918	0.7108
	ato	turnover rate of total capital	410325	0.8875	0.5337	0.0243	7.8714
	cashflow	cash flow ratio	410325	0.0497	0.0747	-1.9377	0.4300
	lev	asset-liability ratio	410325	0.4636	0.2095	0.0075	0.9970
	tq	tobin's q	402660	1.9589	1.1847	0.7488	48.5054
	hhi	herfindahl index	402470	0.2086	0.2633	0.0131	1.0000

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5. Empirical Analysis

5.1. Baseline Regression Analysis

Table 2 below shows the baseline regression of the impact of enterprise digital transformation on export product quality. Among them, (1) is listed as the result of fixed effect of controlling enterprise, year and export products. It can be seen that dig coefficient is 0.1337, which is significantly positive at 1% level, indicating that enterprise digital transformation can significantly improve the quality of its export products. (2) is listed as other characteristics of control enterprises, and it is found that the significance and direction of dig regression coefficient have no change, and it is still significantly positive at 1% level. In columns (3) and (4), the fixed effect of provinces and cities and other firm control variables were added, and the significance and direction of dig coefficient remained unchanged and passed the 1% significance level test. The results show that the digital transformation of Chinese enterprises can significantly promote the quality of their export products.

Table 2. Basic regression result.

Variable	(1)	(2)	(3)	(4)
dig	0.1337*** （0.0489）	0.1932*** （0.0499）	0.1965*** （0.0501）	0.2048*** （0.0512）
size	-	-0.0035*** （0.0008）	-0.0038*** （0.0009）	-0.0032*** （0.0010）
age	-	-0.0196*** （0.0053）	-0.0203*** （0.0054）	-0.0203*** （0.0055）
roe	-	0.0054** （0.0025）	0.0053* （0.0028）	0.0030 （0.0028）
ato	-	-	-0.0005 （0.0013）	0.0006 （0.0014）
cashflow	-	-	0.0097** （0.0040）	0.0075* （0.0041）
lev	-	-	0.0044 （0.0032）	0.0033 （0.0033）
tq	-	-	-	0.0003 （0.0002）
hhi	-	-	-	-0.0031*** （0.0011）
cons	0.0316*** （0.0003）	0.1290*** （0.0200）	0.1337*** （0.0216）	0.1204*** （0.0228）
Firm fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Product fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	No	Yes	Yes	Yes
Observations	410325	410325	410325	394814
R-squared	0.0976	0.0977	0.0978	0.1021

Note: Small brackets () are robust standard error, *, ** and *** respectively indicate significant at the level of 10%, 5% and 1%, the same below.

5.2. robustnesstest

5.2.1. Instrumental Variable Regression

This paper mainly verifies the impact of digital transformation on the quality of export products, but this inspection mechanism may have endogenous problems. Although the empirical results show that enterprise digital transformation may improve the quality of export products, on the other hand,

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enterprises with high quality export products have stronger willingness or capital to adopt digital technology to promote enterprise digital transformation, which leads to the deviation of reverse causation. In order to alleviate the endogeneity problem, the two-stage least square method (2SLS) was used in this paper to reestimate, so as to reduce the deviation of the endogeneity problem to the research results.

Firstly, the average level of digital transformation of enterprises in the same industry in the region is selected as the instrumental variable. In theory, the digital transformation level of the same industry in the region where the enterprise is located can promote the adoption of digital technology and meet the conditions of correlation with the core explanatory variables. But on the other hand, the degree of digital transformation in the same industry in the same region does not directly affect the quality of export products of enterprises, which meets the exogenous conditions. Secondly, the number of Internet access ports in the province where the enterprise is located is selected as the instrumental variable of digital transformation. The number of Internet access ports reflects the degree of residents' participation in the Internet in each province. The higher the degree of Internet is, the more advanced the digital technology is in the province. The number of Internet access ports does not directly affect the quality of enterprises' export products, but can stimulate enterprises to carry out industrial digital empowerment, improve the level of digital transformation, and also satisfy the exogeneity hypothesis of instrumental variables. Finally, referring to Goldsmith-Pinkham et al. (2020) [28], the degree of digital transformation of all enterprises in the province where the enterprise is located is added up to construct instrumental variables for the overall digital transformation of the province where the enterprise is located. Regression of instrumental variables is shown in Table 3 below. It can be seen that the regression results of the three instrumental variables all showed positive dig coefficients and passed the significance level test of more than 5%. In addition, the statistics of Kleibergen-Paap rk LM and the critical value of Kleibergen-Paap rk Wald F both reject the null hypothesis, indicating that the instrumental variables reject the unidentifiable and weakly identifiable tests respectively, and the selection of instrumental variables is reasonable.

Table 3. Instrumental variable regression.

Variable	（1）	（2）	（3）
dig	1.9732***	1.9707***	0.6367**
	（0.4112）	（0.4591）	（0.2851）
Kleibergen—Paap rk LM	1623.145	4196.642	1.1e+04
	[0.0000]	[0.0000]	[0.0000]
Kleibergen—Paap rk Wald F	2842.891	4583.238	1.1e+04
	{16.38}	{16.38}	{16.38}
control variable	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Product fixed effect	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes
Observations	394814	394814	394814

Note: Brackets [] are chi-square p-values used to test whether instrumental variables are unidentifiable, and curly brackets {} represent 10% critical values used to identify weakly identifiable instrumental variable statistics, the same below.

In this paper, core variables were replaced and then returned to test the rationality of the model construction. First, precise word frequency interception is no longer used for core explanatory variables, so as to expand the length of MD&A and construct new digital transformation indicators. Secondly, the quality of export products is not weighted and standardized export product quality indicators are directly used. Finally, change the weighting method of export product quality and adopt the weighting method of trade amount instead of trade volume. The results are shown in Table 4. It can be seen that the dig coefficient is still significantly positive after replacing the core variable.

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Table 4. Replacement variable regression.

Variable	Replace the explanatory variable	Replace the explained variable	
	(1)	(2)	(3)
dig	0.0020***	0.3469***	0.1610***
	(0.0005)	(0.1157)	(0.0474)
control variable	Yes	Yes	Ys
cons	0.1205***	0.3621***	0.1165***
	(0.0229)	(0.0469)	(0.0216)
Firm fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Product fixed effect	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes
Observations	394814	394814	394814
R-squared	0.1021	0.0482	0.1093

5.2.2. Other Robustness Tests

A series of other robustness tests were also conducted in this paper. First, core variables of the samples were treated with 1% tail reduction to avoid bias of the regression results caused by outliers. Secondly, the financial crisis had a great impact on global trade, which also caused bias to the regression estimate, so the sample data of 2008 and 2009 were excluded. Finally, since processing trade is a re-export business activity, which cannot fully reflect the product quality of enterprises, this paper only retains general trade samples and excludes other trade mode samples, so as to better estimate the impact of enterprises' digital transformation on the quality of export products. The results are shown in Table 5 below. After the above robustness test, dig coefficient is still significantly positive, indicating that the model construction is reasonable.

Table 5. Other robustness tests.

Variable	Tail reduction treatment	Strip out the effects of the financial crisis	Only keep the general mode of trade
	(1)	(2)	(3)
dig	0.2048***	0.3087***	0.1284**
	(0.0513)	(0.1183)	(0.0532)
control variable	Yes	Yes	Yes
cons	0.1207***	0.3699***	0.1139***
	(0.0229)	(0.0501)	(0.0238)
Firm fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Product fixed effect	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes
Observations	394814	371380	326268
R-squared	0.1000	0.0476	0.1118

5.3. Inspection of Channels and Mechanisms

In the previous part, we verified that the digital transformation of enterprises has an obvious promoting effect on the quality of their export products, and this part verifies the channels and mechanisms. According to the above theoretical analysis, the digital transformation of enterprises provides more innovation modes to improve the innovation efficiency of enterprises, and the digital technology optimizes the production mode and management mode of enterprises, improves the total factor productivity, and thus improves the quality of enterprises' export products. Next, based on the above logic, we test the following two questions to demonstrate the impact mechanism of enterprise

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digital transformation and export product quality: First, whether enterprise digital transformation can indirectly promote the improvement of export product quality by improving enterprise innovation performance; Second, whether enterprises' digital transformation can indirectly promote the quality improvement of export products by improving total factor productivity. The results are shown in Table 6 below.

Table 6. Inspection of channels and mechanisms.

Variable	Innovation performance	Total factor productivity
	(1)	(2)
dig	11.1893***	14.5559***
	(0.6585)	(0.5099)
Kleibergen-Paap rk LM	770.931	1623.145
Kleibergen-Paap rk Wald F	506.725	2842.942
control variable	Yes	Yes
Firm fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
Product fixed effect	Yes	Yes
Region fixed effect	Yes	Yes
Observations	337185	394724

5.3.1. Innovation Performance Mechanism

According to the theoretical analysis above, enterprise digital transformation can form an open innovation, improve the possibility of innovation cooperation, effectively reduce the cost of research and development, so as to improve the efficiency of research and development, make better use of innovation resources, improve the technical level of products, and help enterprises to improve the quality of export products. Iv-2sls was used to empiricly test the impact of digital transformation on innovation performance, and the average level of digital transformation in the same industry was selected as the instrumental variable. The results were shown in Column (1). The results show that enterprise digital transformation can significantly improve innovation performance and pass the 1% significance level test, which is also consistent with Lyytinen K et al. (2016) [29]. Therefore, innovation performance is verified in the intermediary mechanism between enterprise digital transformation and export product quality.

5.3.2. Total Factor Productivity Mechanism

According to the theoretical analysis above, digital transformation of enterprises can improve the total factor productivity of enterprises by improving the management mode of enterprises, enhancing the intelligent production and manufacturing level of enterprises, and expanding the scale economy effect of enterprises, and the improvement of total factor productivity of enterprises is conducive to reducing the production and operating costs of enterprises, so that enterprises have more costs to improve products and develop new products. And improve the quality of export products. Similarly, IV-2SLS is used to empiricism test the impact of digital transformation on total factor productivity of enterprises, and the average level of digital transformation of enterprises in the same industry is selected as instrumental variable. The results are shown in Column (2). The results show that enterprise digital transformation can significantly improve the total factor productivity, and pass the 1% significance level test. Therefore, the mediating mechanism of total factor productivity in enterprise digital transformation and export product quality has been verified.

5.4. Heterogeneity Analysis

This part was divided into heterogeneity analysis, and the results were shown in Table 7 below. The heterogeneity analysis mainly includes three aspects: 1. Based on the heterogeneity analysis of enterprise ownership. Enterprises can be divided into foreign-funded enterprises and domestic-

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funded enterprises according to their ownership. Foreign-funded enterprises and domestic-funded enterprises have different driving forces in digital transformation, which will have different impacts on the quality of export products. Therefore, the virtual variable owner is constructed, and the assignment method is 1 and 0, that is, if it is a foreign-funded enterprise, the assignment is 1, otherwise it is 0, and the assignment is the same for a domestic enterprise. Column (1) and (2) respectively show the regression results of foreign-funded enterprises and domestic enterprises. It can be seen that the digitalized transformation of domestic enterprises has stronger export product quality improvement effect than that of foreign-funded enterprises, which may be because most foreign-funded enterprises are backward production capacity enterprises in developed countries and their industrial technology level is not high, thus affecting the digitalized transformation's effect on the quality improvement of export products. 2. Based on regional heterogeneity analysis. According to the provinces and cities where the enterprises are located, they are divided into eastern region and central and western region [1] , the assignment method also assigns values of 1 and 0. China's regional development presents a cascade distribution in the east and west, so the development degree of digital economy will also be different, and the quality effect of export products of enterprises' digital transformation will have regional heterogeneity. Column (3) and (4) respectively show the heterogeneity results of the eastern and central regions. It can be seen that compared with the central and western regions, the digital transformation of enterprises in the eastern region has a more obvious effect on improving the quality of export products. 3. Based on technical heterogeneity analysis. Enterprises are divided into technology-intensive and non-technology-intensive enterprises according to their technology-intensive degree. Technology-intensive enterprises are more motivated to adopt digital technology, which will affect the quality of export products. The technology-intensive classification standard is the median ratio of R&D personnel to the total number of employees, which is calculated as 0.1156. If the value exceeds this value, it indicates that the enterprise is technology-intensive, and the assignment method is 1 and 0. From column (5) and (6), it can be seen that the digitalized transformation of technology-intensive enterprises has more obvious effect on improving the quality of export products.

Table 7. Heterogeneity analysis.

Variable	Ownership Heterogeneity		Regional Heterogeneity		Technical Heterogeneity	
	foreign capital	domestic capital	The eastern region	The central and western regions	technology intensive	non-technology-intensive
	(1)	(2)	(3)	(4)	(5)	(6)
dig	0.2022** (0.0948)	0.2386*** (0.0607)	0.2578*** (0.0575)	0.0344 (0.1226)	3.2488** (1.3926)	-1.7769 (2.6642)
control variable	Yes	Yes	Yes	Yes	Yes	Yes
cons	0.2065** (0.0801)	0.1149*** (0.0244)	0.1357*** (0.0278)	0.0866** (0.0416)	-2.9151*** (1.0264)	1.1393 (0.7977)
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Product fixed effect	Yes	Yes	Yes	Yes	Yes	Yes

[1] Eastern region: Beijing, Tianjin, Hebei, Shandong, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan, etc., due to the selection of A-share listed companies, Hong Kong, Macao and Taiwan regions are not taken into account, and other provinces and cities are central and western regions.

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Region fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	64685	330129	312149	82665	34732	34716
R-squared	0.1672	0.0991	0.0858	0.2128	0.2619	0.1698

5.5. Further Analysis: The Masking Effect of Income Share

Research shows that digital transformation will increase the demand for high-skilled labor, while conventional low-skilled labor will be replaced by artificial intelligence (Acemoglu D and Restrepo P, 2018) [30]. As an applied technology, digital transformation itself has an obvious "skill-based technological progress" effect (Autor D H and Murnane L, 2003) [31], thus enhancing the wage bargaining power of unconventional labor, and thus widening the salary gap between top and bottom employees of enterprises. The widening of the salary gap within an enterprise is likely to cause discontent among employees at the bottom, thus affecting work efficiency (Cowherd D M and Levine D I, 1992) [32]. Such reduction of work efficiency may have a negative impact on the quality of enterprise products, and then affect the quality of export products. Therefore, there is a reverse effect between the intermediary mechanism and the direct effect mechanism, that is, the uneven share of enterprise income will have a masking effect on the quality upgrade effect of enterprise digital transformation.

Step1: We explore the mechanism effect of changes in internal revenue share on digital transformation and export product quality. The internal income share of enterprises is investigated from two perspectives. On the one hand, the internal salary gap (lnequapay) is used as the index of the internal salary gap, and the ratio of the average salary of management and the average salary of employees is taken as logarithm. On the other hand is the average salary level of ordinary employees (lnwage), which is measured by dividing cash paid to and for employees by the number of employees and taking logarithm.

Step2: To verify the above mechanism, the following regression model is constructed:

$$lnequapay_{ijt} = \alpha_0 + \alpha_1 dig_{it} + vX_{it} + \delta_i + \delta_j + \delta_p + \delta_t + \varepsilon_{ijt} \quad (8)$$

$$lnwage_{ijt} = \gamma_0 + \gamma_1 dig_{it} + vX_{it} + \delta_i + \delta_j + \delta_p + \delta_t + \varepsilon_{ijt} \quad (9)$$

Step3: IV -- 2SLS was adopted for estimation, and the above model was mainly concerned with and coefficient. The results are shown in Table 8 below. As can be seen from column (1).

Table 8. Further analysis: the masking effect of income share.

Variable	**Intra-firm Compensation Dispersion**	**Average Salary Level of Enterprise Employees**
	(1)	**(2)**
dig	46.7025***	-43.5994***
	(1.6504)	(1.5099)
lnequapay	-	-
lnwage	-	-
Kleibergen-Paap rk LM	1620.142	1620.142
	[0.0000]	[0.0000]
Kleibergen-Paap rk Wald F	2837.910	2837.910
	{16.38}	{16.38}
control variable	Yes	Yes
Firm fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
Product fixed effect	Yes	Yes
Region fixed effect	Yes	Yes
Observations	393479	393479

6. Empirical Results

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6.1. Case Information

As an important driving mode of economic development, digital transformation has been an important path for countries to move towards industry 4.0. In particular, coastal areas such as Guangdong, which occupy the advantages of economy, geography and resources, have always been in the forefront of digital transformation. For a long time, the economy of Guangdong Province has been developing rapidly with high quality in China, and the contribution of small and medium-sized enterprises can not be ignored. The number of small and medium-sized manufacturing enterprises in Guangdong Province accounts for 95% of the total number of manufacturing enterprises. It can be seen that small and medium-sized enterprises are not only the main body of digital transformation, but also the focus and difficulty of transformation. In China's 14th five year plan, the development goal of the digital economy is to move towards a comprehensive expansion period by 2025 and a prosperous and mature period by 2035. This makes small and medium-sized manufacturing enterprises must implement digital transformation under the new national economic development requirements. For traditional manufacturing enterprises, they try to start with the purchase of digital equipment and gradually realize intelligent manufacturing. For emerging technology enterprises with inherent advantages, they will choose to carry out digital reform in terms of organizational reform and talent skills training.

However, due to differences with large enterprises in various aspects, these small and medium-sized manufacturing enterprises have encountered great difficulties in the process of digital transformation. Under the pressure caused by the general environment of industrial digital transformation, most enterprises have not clearly defined the digital transformation objectives, do not understand their own preparations, still less do they know the methods and steps of digital implementation. In addition, the enterprises have limited resources and poor risk resistance, so they either dare not implement digitization at will or may blindly reform. Wrong decisions can waste resources. In addition, digital transformation is a system engineering, involving every aspect of the enterprise. Enterprises cannot evaluate the relationship between these standards. In this study, DEMATEL-ANP is used to simplify the complex relationship between these standards by providing the structure of digital maturity, and determine the importance of each standard. Then, the fuzzy comprehensive evaluation method is used to evaluate and compare the typical industries, and the relationship between the indicators of digital maturity is analyzed in depth to provide effective guidance for the digital transformation of small and medium-sized manufacturing enterprises.

7. Conclusions and Enlightenment

7.1. Research Conclusion

This paper focuses on the theoretical mechanism and action mechanism of digital transformation on the improvement of export product quality of manufacturing enterprises, and uses the export data of foreign trade enterprises and the annual report data of listed foreign trade enterprises from 2007 to 2015 to measure the export product quality and enterprise digital transformation index, and empirically tests the impact of digital transformation on the quality of export products. It is found that enterprise digital transformation can significantly improve the quality of export products, and there are two mechanisms of innovation efficiency and total factor productivity to improve the quality of export products. In the heterogeneity analysis, the quality improvement effect of export products in digital transformation of domestic enterprises is greater than that of foreign enterprises, and the quality improvement effect of export products in digital transformation of technology-intensive enterprises in eastern regions is more significant. In the further analysis, the digital transformation of enterprises will significantly expand the internal salary gap of employees, which may have an adverse impact on the quality of export products, namely, there is a masking effect.

7.2. Policy Inspiration

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7.2.1. Comprehensively Promote the Digital Transformation of Enterprises, and Accelerate the Deep Integration of Digital-Related Technologies into All Aspects of Manufacturing Enterprises

Fully recognize the status quo of Chinese manufacturing industry and new development opportunities brought by digital transformation for enterprises, vigorously support the digital transformation of manufacturing enterprises, and truly integrate advanced digital technology into enterprise business model innovation, including the optimization and upgrading of R&D mode, procurement mode, production mode and sales mode, accelerate the innovation and research and development of new products. Comprehensively improve the quality of foreign trade enterprises export products, so that our manufacturing enterprises have the ability to develop continuously.

7.2.2. The Transformation of Digital Transformation Thinking

The difficulties of digital transformation of manufacturing enterprises include long cycle, slow effect, high transformation investment and poor transformation effect. The reason is that manufacturing enterprises should change their understanding of digital transformation from tool transformation thinking to "real digital enterprise" thinking. Digital transformation is not a technical problem at the root, but a transformation of the overall strategy of the organization. The digital transformation of enterprises should have a strong desire for transformation, formulate transformation strategies and objectives, select the scene and implement the distribution, dare to trial and error, and unswervingly invest resources.

7.2.3. Establish An Open Innovation Ecosystem for Digital Technology Industry and Manufacturing Application Scenarios

We should actively promote the construction of industrial integration and innovation of digital technology industry and manufacturing industry. Digital technology enterprises, R&D personnel of digital technology platform enterprises and technical personnel of manufacturing enterprises should jointly develop enterprise digital platform technology and digital transformation solutions, so as to promote the implementation of digital transformation. By providing an open innovation platform, traditional manufacturing enterprises establish an open innovation ecosystem around their own products, and digital technology research and development enterprises provide original ecological technology supply to attract digital technology developers to conduct technology research and development of new functions within the ecosystem, and accelerate digital upgrading through technology internalization and application.

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Appendix A

Table A1. Digital transformation index.

Keywords of digital transformation
Information;networking;data;Internet;intelligence;informatization;artificial intelligence; digitalization; intelligent key technologies; information technology; e-commerce; communications; core technologies; industrial chain; virtual reality; networking; broadband; machines; information security; information systems; data centers; connectivity; cyberspace;industry-university-research;human-machine;interaction;data sharing; data security; number Data base; sensor; e-government; data analysis; wireless; network; e-commerce; Internet security; information network; integrated circuit; information network; public data; technology development; software and hardware; information industry; radio and television; radio and television; technology transformation; numerical control; energy network; network coverage; electric; algorithm; communication network; cross-media; computer; gateway; automation; television network; Service network; data service; data flow; application software; service network; data processing; data mining; digital television; network facilities; broadband access; data management; information management; online education; server; computing technology; automatic control; processors; development tools; control technology; network services; network equipment; product development; electronic information; invention patents; high Technology; high and new technology; monitoring network; portal network; portal website; live broadcast; smart phone; intelligent network; networking; navigation system; multimedia; Internet protocol; base station; agricultural remote sensing; human-computer interaction; satellite communication; radio; wireless network; wireless network; information port; domain name;terminal products; bit; coding; electronic products; management information system; national defense technology; communication satellite; information flow; virtualization; All Access; government network; intelligent algorithm; China Association for Science and Technology; Business intelligence; image understanding; investment decision aid system; intelligent data analysis; intelligent robotics; machine learning; deep learning; semantic search bio metrics; face recognition; speech recognition; authentication; automatic driving; natural language processing; big data; text mining; data visualization Integration; heterogeneous data; credit information; augmented reality; mixed reality; block-chain; digital currency; distributed computing; differential privacy technology; intelligent financial contracts; cloud computing; stream computing; graph computing; memory computing; cognitive computing; fusion architecture;100 million level concurrency; Internet of Things; information physical system; mobile Internet; industrial Internet; mobile Internet; Internet medical; mobile payment; Third party payment; intelligent energy; Internet connection; intelligent wearable; intelligent agriculture; intelligent transportation; intelligent medical care; intelligent customer service; intelligent home; intelligent investment; intelligent cultural travel; intelligent environmental protection; intelligent power grid; intelligent marketing; digital marketing unmanned retail; Internet finance; digital finance; financial technology; quantitative finance; open banking; digital technology;application data; digital; digital number Data management; data network; data platform; data science; digital control; digital communication; digital network; digital intelligence; digital terminal; cloud ecology; cloud service; cloud platform; e-commerce mobile Internet; industrial Internet; Internet solutions; Internet technology; Internet thinking; Internet action; Internet business; Internet mobile; Internet application; Internet marketing; Internet strategy; Internet platform; Internet model; Internet business model; Internet ecology; e-commerce mobile Internet; machine learning Internet business model; cloud storage;

Internet+;relational database; blockchain; business intelligence; Business intelligence; industry 4.0. Platform economy; digital creativity; digital business; digital technology; data empowerment;new industrialization;intelligent manufacturing; intelligent technology; intelligent terminal; robotics; ecological collaboration; knowledge management; online; network security;network retail; multi-party security computing; brain-like computing; green computing digital supply chain; intelligent supply chain; supply chain.

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