Digital Economy and Sustainable Development

RESEARCH

Open Access

Digital intermediate product imports and firms'export quality: evidence from China

Wanwan Ren[1], Tianhan Lin[2*] and Yuqian Hao[1]

Abstract

Based on the '*Statistical Classification of Digital Economy and Its Core Industries (2021)*' published by the National Bureau of Statistics of China, this paper proposes a more accurate method to identify digital intermediate products by matching China Industrial Classification code with Harmonized System code, and investigates the connection between digital intermediate product imports and firms' export quality using China's firm-level data from 2000 to 2013. Our estimations show that digital intermediate product imports can significantly promote the quality of firms' export products through both the productivity channel and the quality production capacity channel, and the conclusion still holds after a series of endogeneity tests and robustness tests. Moreover, considering the heterogeneity effect of digital intermediate product imports with different characteristics, we find that high-quality and diversified digital intermediate product imports will strengthen the quality upgrading effect of firms' export products, while the effect of improving the technical content is not significant. This paper provides a new path for firms, especially those in developing countries, to upgrade export quality.

Keywords Digital Intermediate Product, Export Product Quality, Productivity, Quality Production Capacity

1 Introduction

As the global economic pattern is being reshaped by the development of the digital economy, more and more firms use digital products such as robots and automated machines to construct an intelligent manufacturing industry system (Bastos et al. 2020), and digitally augment previously non-digital products (Porter and Heppelmann 2015; Ardito et al. 2017). Digital products have become the core of the digital economy (Loebbecke 2003), the key to cultivate international competitiveness in the process of globalization (Zhang et al. 2023). For developing countries, who have long been at the low end of foundry production along the global value chain, taking the digital economy opportunity is quite crucial for their development. Digital intermediate products, not only the main carrier of digital technology and digital resources (Huang and Wang 2022), but also an indispensable input factor in the production, are playing an important role in promoting the digital transformation and upgrading of firms. Given that developing countries have difficulty achieving technological improvement in a short period through their own accumulation of capital and factors, and largely rely on foreign technology sources (Hausmann and Rodrik 2003), importing digital intermediate products become an available and critical channel for developing countries to improve the export product quality. Existing studies have confirmed that imports of intermediates could promote the quality of firms' export products through channels such as "quality effect", "technology spillover effect" and "product category effect" (Bas and Strauss-Kahn 2015; Xu and Mao 2018; Song et al. 2021; Feng et al. 2016). And compared with the temporary import of intermediate goods, continuous import has a more significant effect on

*Correspondence:
Tianhan Lin
lintianhan0317@163.com
[1] School of Economics, Zhejiang Gongshang University, Hangzhou, Zhejiang Province, China
[2] School of Business, Shanghai University of Finance and Economics, Yangpu District, No.777 Guoding Road, Wujiaochang Street, Shanghai, China

improving the quality of export products (Liu et al. 2017). In the context of the digital economy, it is necessary to re-examine the export product quality effects of digital intermediate product imports.

The concept of digital products has been enriched over time. In the `*E-Commerce Work Plan*` (WTO 1999) and US-Chile Free Trade Agreement reached in 2003, digital products are images, computer programs, videos, audio recordings, texts and other content products that are digitally encoded and transmitted electronically. United Nations Conference on Trade and Development (UNCTAD 2001) refers the digital product as any digitally encoded product that is transmitted electronically or stored on a physical carrier. And agreements such as the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP 2018) and the US-Mexico-Canada Agreement (USMCA 2018) basically follow the digital product definition of UNCTAD. Digital products under this type of definition do not have entities, and are also called digital-intangible products, which exist in the digitally encoded format, and can be transmitted electronically or stored on the physical carriers. Trade in such digital-intangible products has been so difficult to quantify that existing international trade agreements generally do not tax them.[1] Further, according to `*Handbook on Measuring Digital Trade*` jointly issued by the WTO, OECD and IMF, and the `*White Paper on Digital Economy Development*` issued by the China Academy of Information and Communications Technology (CAICT) from 2015 to 2019, electronic products produced using digital technology are identified as digital-physical products (Liu and Sun 2021; Huang and Wang 2022; Yu et al. 2022), which are used to acquire, transmit and process digital information, execute digital information instructions, etc. And, the digital intermediate products we focus on are the components of digital-physical products, referring to intermediate products produced by digital technology, such as sensors, integrated circuits and other electronic components, which deeply penetrate and integrate the attributes of digital technology. Digital intermediate products can produce extensive technology spillovers as intermediate products, and the embedded digital technology has unique low copy cost characteristics (Huang and Wang 2022). After the firm completes the research and development of the product and puts it into production, the marginal cost of each additional unit of product produced will be very low. Further, in addition to being a production input for the final product, the digital attributes of digital intermediate products determine that they can participate in the firm's production process, optimize resource allocation, and improve operational levels.

With the enrichment of definition, accurately identifying digital products based on technical attributes has become an important topic. Liu and Sun (2021) identifies the HS codes of digital-physical products by searching keywords, and find that digital-physical product imports can significantly promote firm innovation through technology spillovers. Based on the similar method, Huang and Wang (2022), Yu et al. (2022) find that digital-physical product imports have positive effects on digital innovation and exporting technological complexity. Zhang et al. (2023) identifies digital products through CIC-HS codes matching and manual screening, and find that imported digital product inputs is positively correlated with export quality. In all these studies, the accuracy of these measurements depends on the definition of digital products and the selection of keywords, which are easily affected by subjective factors. Thus, we first improve the method of identifying digital intermediate products which makes a useful supplement to the existing digital product trade accounting methods, according to the *'Statistical Classification of the Digital Economy and Its Core Industries (2021)'* (SCDECI) issued by the National Bureau of Statistics of China (NBSC) which classifies the digital product manufacturing industry[2] based on the China Industrial Classification (CIC) codes.

Second, we estimate how the digital intermediate product imports affects firms' export quality, which provides an addition to the existing researches. By combining the Chinese Manufacturing Firms Database and the China Customs Trade Database from 2000 to 2013, we find that the import scale and import number of digital intermediate products of China continue to grow, and the digital intermediate product imports can promote firms' export quality. Specifically, digital intermediate product imports stimulate firms' export quality upgrades through two channels: productivity and quality production capacity. To ensure the unbiasedness of the results, we adopt a propensity score matching (PSM) panel estimation, several IVs, and a series of robustness tests. In addition, the positive effect of digital intermediate product imports holds for firms with different ownership and trade types, as well as firms from different industries and cities. Promoting export quality through digital intermediate product imports is the key to the virtuous trade cycle for developing countries, as digital intermediate products

[1] Agreements such as UJDTA, USMCA, and CPTPP explicitly exempt electronic transmissions from tariffs.

[2] Digital product manufacturing industry, including manufacturing industries such as computer, communication and radar equipment, industrial robot, digital media equipment and electronic component.

are more likely to generate knowledge spillovers in the production.

Third, we consider the heterogeneous effects of digital intermediate product imports with different characteristics, which may provide more targeted suggestions for firms to improve the quality of export products. We measure the digital intermediate product imports from the perspective of technological content, diversification, and quality. Specifically, we find that export quality improved more from importing high-quality and diversified digital intermediate inputs, rather than high technical content.

The rest of the paper is structured as follows. Section 2 illustrates how the digital intermediate product imports affects the firms' export quality through the productivity and quality production capacity channels. Section 3 describes the empirical strategy and data. Section 4 presents the results of baseline regression, self-selection bias treatment, endogeneity treatment, and robustness test. Section 5 further empirically tests the theoretical mechanism of how the digital intermediate product imports affects the firms' export quality. Section 6 discusses the heterogeneous effects of digital intermediate product imports with different characteristics. Section 7 is the conclusion.

2 Theoretical analysis

According to Hallak and Sivadasan (2009), firms' optimal export product quality is given by the following expression:

$$\lambda_{fct}^{g}(\varphi_{ft},\xi_{ft})=\left[\frac{1-\beta}{\alpha}\left(\frac{\sigma-1}{\sigma}\right)^{\sigma}\left(\frac{\varphi_{ft}}{C}\right)^{\sigma-1}\frac{\xi_{ft}}{F}\frac{E_{ct}^{g}}{P_{ct}^{g}}\right]^{\frac{1}{\alpha'}} \tag{1}$$

where λ_{fct}^{g} is the quality of product g exported by firm f to country c in year t. φ_{ft} and ξ_{ft} are, respectively, the "productivity" and "quality production capacity" of firm f in year t. Productivity reduces firms' variable production costs given quality. Quality production capacity indexes firms' ability to develop high quality products paying low fixed costs.α and β are quality elasticity, $\alpha>(1-\beta)(1-\sigma)$, $0<\beta<1$, $\alpha'=\alpha-(1-\beta)(1-\sigma)>0$. $\sigma>1$ is the elasticity of product substitution, C and F are constants, representing the unit price of variable input and fixed input respectively.E_{ct}^{g}(exogenously given) is the total expenditure on product g in country c in year t. P_{ct}^{g} is the "price aggregator" of product g in country c, year t.

Referring to Ma and Wu (2016), take the logarithm on both sides of Eq. (1), and use the ratio (ω_{fct}^{g}) of the value of product g exported by firm f to country c in year t to the value of the total export product as the weight to add up the product quality to the firm level. The export product quality of firm f in year t can be expressed as:

$$quality_{ft}=\sum_{g=1}^{N_g}\sum_{c=1}^{N_c}\omega_{fct}^{g}ln\lambda_{fct}^{g}=\eta+\frac{1}{\alpha'}lnf+\frac{\sigma-1}{\alpha'}ln\varphi_{ft}+\frac{1}{\alpha'}ln\xi_{ft}+\tau_{ft} \tag{2}$$

where $\eta=\frac{1}{\alpha'}ln\frac{1-\beta}{\alpha}\left(\frac{\sigma-1}{\sigma}\right)-\frac{\sigma-1}{\alpha'}lnc$, $\tau_{ft}=\frac{1}{\alpha'}\sum_{g=1}^{N_g}\sum_{c=1}^{N_c}\omega_{fct}^{g}ln\frac{E_{ct}^{g}}{P_{ct}^{g}}$ is the market factor faced by firm f in year t. It can be seen from Eq. (2) that productivity and quality production capacity are the main sources of heterogeneity in the quality of a firm's export products. The higher the productivity and quality production capacity of a firm, the higher the quality of export products. This paper will take productivity and quality production capacity as the starting point to analyze the impact mechanism of importing digital intermediate products on the quality of firms' export products.

Productivity Channel: importing digital intermediate products may have an impact on the quality of firms' export products by increasing productivity. Digital intermediate products can use digital technology to build a bridge for the flow of data and information within a firm, and realize the ubiquitous interconnection between machines and machines and between machines and people (Lu and Li 2022). It is an important "glue" in each production link. In general, the productivity impact of importing digital intermediate products includes the effect of improving capital and labor output efficiency. (1) Capital output efficiency improvement effect. The input of digital intermediate products can improve the productivity by optimizing the allocation efficiency of capital elements and improving the efficiency of capital output. The import of digital intermediate products expands the range of inputs that firms can choose, enabling firms to allocate resources in both domestic and foreign markets. Bas and Strauss-Kahn (2015) pointed out that firms that use imported intermediates in the production process can obtain lower-cost intermediate inputs globally. By improving production efficiency, the capital output efficiency of firms can be improved. When digital intermediate products are embedded in equipment, digital technology will integrate the firm's hardware equipment, software management system and digital applications. By monitoring the working status of machines and the usage of materials in real time, and adjusting the improper use of factors in real time, firms can optimize the allocation efficiency of capital factors, thereby improving the efficiency of capital output. (2) Labor output efficiency improvement effect. The input of digital intermediate products improves the productivity by reducing the input of labor factors and increasing the efficiency of labor output. The input of digital intermediate products can achieve a high level of numerical control and automation of the production and operation process, reduce the demand for low-skilled labor, simplify the original production management personnel structure of the firm, and improve the labor productivity of the firm by reducing the input of labor factors in the production process (Zhu et al. 2022).

Quality Production Capacity Channel: importing digital intermediate products may have an impact on the quality of firms' export products by improving quality production capacity. (1) Quality transfer effect. As the cutting-edge products of the manufacturing industry, the quality of digital intermediate products imported by firms in developing countries are often higher than that of similar products in the domestic market. Feng et al. (2016) pointed out that quality embedded in imported inputs can facilitate product upgrading. Through the input–output process, the high-quality characteristics of imported digital intermediate products will be transferred to the final product of the firm (Kugler and Verhoogen 2012; Bas and Strauss-Kahn 2015), thereby improving the quality production capacity. (2) Digital innovation effect. Digital innovation refers to the recombination of digital components and traditional input elements to create digital products (Yoo et al. 2010), which endow traditional products with digital attributes such as intelligence and interconnection. Firms embed imported digital intermediate products into traditional products, which can promote digital innovation and improve the quality production capacity. (3) Quality monitoring effect. The input of digital intermediate products can establish a complete data collection system for the entire production process of the firm, strengthen the standardization of the operation of each production link and the real-time control of the quality of the final product (Yu et al. 2022), thereby improving the quality production capacity of the firm. At the same time, detailed data records link raw materials, intermediate products, and finished products with their specific raw material suppliers, production processes, key process parameters, operating equipment, and operators (Lu and Li 2022). When there is a problem with product quality, the firm can trace the source of each link of product production, quickly find and solve the abnormality, so as to ensure product quality and improve quality production capacity. (4) Human capital upgrading effect. Digital intermediate products are technology-intensive production factors, and importing a large number of digital intermediate products will put forward higher requirements for the supporting labor force (Gao and Wang 2020). By increasing the input of high-skilled labor or conducting internal vocational skills training, firms can improve the average quality of the labor force, thereby improving quality production capacity.

Based on the above analysis, we propose the following hypothesis:

> Hypothesis 1: Importing digital intermediate products can improve the quality of firms' export products.
>
> Hypothesis 2: Productivity and quality production capacity are the core channels through which importing digital intermediate products affect the quality of firms' export products.

3 Estimation strategy and data

3.1 Model specification

To identify the effect of importing digital intermediate products on firms' export products,we set up the following regression equation:

$$TQ_{ijft} = \alpha_0 + \alpha_1 lndigi_{ijft} + \beta control_{ijft} + \varphi_i + \varphi_j + \varphi_f + \varphi_t + \varepsilon_{ijft} \quad (3)$$

where TQ_{ijft} measures the export product quality of firm f in year t, i and j are the city and industry to which the firm belongs, respectively;$lndigi_{ijft}$ indicates the import scale of digital intermediate products; $control_{ijft}$ includes a vector of time-varying controls; $\varphi_i, \varphi_j, \varphi_f, \varphi_t$ are the fixed effects of city, industry, firm and time respectively.

3.2 Measurements

3.2.1 Export product quality

We use the demand information regression method of Shi and Shao (2014) to measure the export product quality of firms, the regression model is as follows:

$$lnq^g_{fct} = \chi_{ct} - \sigma lnp^g_{fct} + lndemand_{fct} + \varepsilon^g_{fct} \quad (4)$$

where $\chi_{ct} = lnE_{ct} - lnP_{ct}$ is the market factor of the importing country, controlled by $\varphi_c \times \varphi_t$ (φ_c are dummies for specific countries); $lndemand_{fct}$ denotes the scale of the domestic market of the exporting firm, which is used to control the impact of product's horizontal differentiation on demand; $\varepsilon^g_{fct} = (\sigma - 1)ln\lambda^g_{fct}$ is the residual item, which contains information of product quality ($ln\lambda^g_{fct}$). In addition, considering the endogenous problem when regressing the demand to the product price, we use the average price of the same product exported by firm f to countries other than c in year t as an instrumental variable.

Before Eq. (4) is regressed by product, the data is processed according to the method of Shi and Shao (2014). The product quality expression is as follows:

$$quality^{g}_{fct} = \frac{\widehat{\varepsilon}^{g}_{fct}}{\sigma - 1} \tag{5}$$

Since the quality of different products is not comparable, Eq. (5) is further standardized as follows:

$$r\_quality^{g}_{fct} = \frac{quality^{g}_{fct} - minquality^{g}}{maxquality^{g} - minquality^{g}} \tag{6}$$

where $maxquality^{g}$ and $minquality^{g}$ are the maximum and minimum values of the quality of product g in the whole sample, respectively. By adding up the Eq. (6), the quality of the firm's export products can be obtained:

$$TQ_{ft} = \sum_{g=1}^{N_g} \sum_{c=1}^{N_c} \omega^{g}_{fct} r\_quality^{g}_{fct} \tag{7}$$

where ω^{g}_{fct} is the ratio of product g exported to country c in total export value of firm f in year t, used to weight the product quality to the firm level.

Import scale of digital intermediate products. Given that most intermediate products are physical products, we focus on the accounting method for the import of digital-physical intermediate products. Liu and Sun (2021) searches the HS codes of digital products through keywords, and measures the import scale of digital products for the first time. Further, Yu et al. (2022), Huang and Wang (2022) improve this method by weighting the network readiness index and extracting keywords of digital products based on word frequency analysis respectively. However, this method is easily affected by subjective factors, whether it is in the digital products' keywords extraction link or in the manual screening of digital products.

Different from the method of Liu and Sun (2021), based on the SCDECI issued by the NBSC, we re-identify and compute the import scale of digital intermediate products through code conversion. The list of digital products identified based on this method is more objective and accurate. SCDECI fully draws on the methods of relevant international institutions on the classification of the digital economy, and refers to the *`Statistical Classification of New Industries, New Business Forms and New Business Models (2018)`* and *`Classification of Strategic Emerging Industries (2018)`*, *`Interim Provisions on the Statistical Classification of Information-related Industries`* and other relevant statistical classification standards reflect various basic activities closely related to digital technology to the greatest extent. Specifically, based on the *`National Economic Industry Classification` (GB/T 4754–2017)*, SCDECI provides 4-digit CIC codes of relevant industry for the purpose of providing digital products. We match the industry code of the digital product manufacturing industry with the HS6-digit code and the BEC code to identify the list of digital intermediate products. Based on the list of digital intermediate products, we use the Chinese customs data to measure the import scale of digital intermediate products (*lndigi*, which is the result of adding 1 to the import value of digital intermediate products and taking the logarithm.) by firms.

Based on the matching data of the Chinese Manufacturing Firms Database and the China Customs Trade Database, we measure China's digital intermediate product imports and export product quality. Figure 1 shows

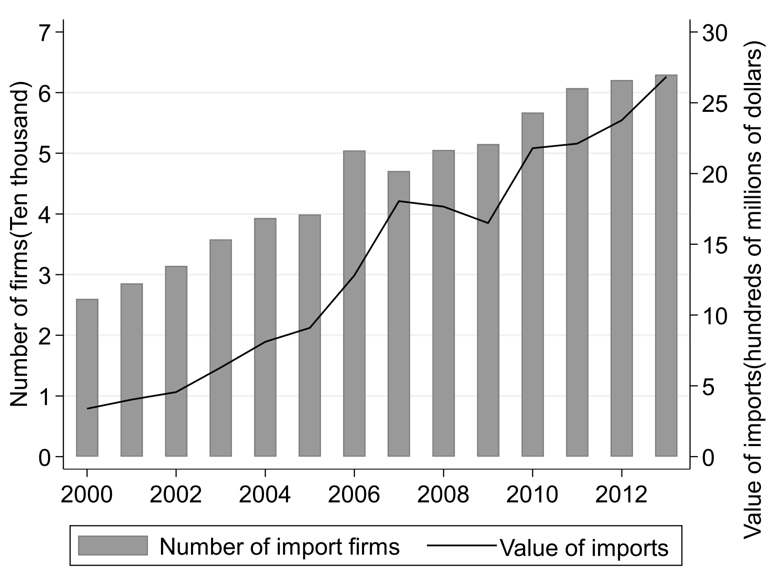

Fig. 1 Trend of digital intermediate imports in China from 2000 to 2013

Table 1 Summary statistics

Variable		Mean	Std.dev.	Min	max	Obs
TQ	Export product quality	0.6440	0.1251	0	1	326,795
lndigi	Import scale of digital intermediate products	0.5592	1.4493	0	12.6413	326,795
lncapint	Capital intensity	3.3785	1.3477	-6.5225	12.3679	325,272
lnsize lnsize	Firm size	10.4405	1.4169	5.0113	18.8473	326,786
lnage lnage	Firm age	2.1499	0.6434	0	7.6054	326,757
subsidy subsidy	Government subsidy	0.1844	0.3878	0	1	326,698
profit	Capital return	0.0811	0.1935	-3.6675	15.5688	326,719
leverage	Leverage ratio	0.5470	0.2621	-5.1923	9.4391	326,753
foreignshare	Share of foreign capital	0.2063	0.1242	0	0.8753	326,795
lnentrybarrier	Entry barrier	10.8687	0.8058	8.9013	16.2715	326,795
HHI	Competition	0.0139	0.0281	0.0006	0.9851	326,795
agglomeration	Degree of agglomeration	0.0287	0.0347	-0.1957	0.7459	326,795

that from 2000 to 2013, the average annual growth rate of China's import of digital intermediate products is about 18.3%, and the average annual growth rate of the number of firms importing digital intermediate products is about 7.3%. The scale of China's import of digital intermediate products and the number of firms importing digital intermediate products are showing rapid growth overall. From 2008 to 2009, the growth of imports of digital intermediate products showed a downward trend, which may be related to the global economic crisis in 2008.

3.2.2 Other control variables

Firm characteristic variables include: Capital intensity (*lncapint*), the logarithm of the ratio of fixed assets to the number of employees; Firm size (*lnsize*), the logarithm of the total assets of the firm; Firm age (*lnage*), the logarithm of the current year minus the year firm opened plus 1; Government subsidy (*subsidy*), 1 when the firm has government subsidy income, and 0 otherwise; Capital return (*profit*), the ratio of firm net profit to total assets; Leverage ratio (*leverage*), the ratio of total liabilities to total assets of the firm. The selection of industry characteristic variables mainly include: Share of foreign capital (*foreignshare*), the ratio of foreign capital to total capital; Entry barrier (*lnentrybarrier*), the logarithm of the average fixed assets of firms; Competition (*HHI*), Herfindahl Index calculated by firm sales; Degree of agglomeration (*agglomeration*), measured by the Ellison-Glaeser Index. The above industry characteristic variables are all calculated at the level of the 4-digit CIC code.

3.3 Data resource and description

3.3.1 Data resource

The data used in this study mainly comes from the matching data of the Chinese Manufacturing Firms Database and the China Customs Trade Database. Referring to Zhang et al. (2013), we match the Chinese Manufacturing Firms Database and the China Customs Trade Database successively according to the firm name, firm zip code plus the last 7 digits of the telephone number. Further, we process the matched firm samples as follows: delete samples with negative values in fixed assets, total assets, total industrial output value, industrial added value, industrial sales and export delivery values; delete samples whose total assets are less than fixed assets; delete samples whose annual average number of practitioners is less than 8; refer to Brandt et al. (2012) to uniformly adjust the 4-digit code of the industry (CIC), and use the deflator (based on 1998) provided by them to process the data.

3.3.2 Data description

Summary statistics for the sample are presented in Table 1.

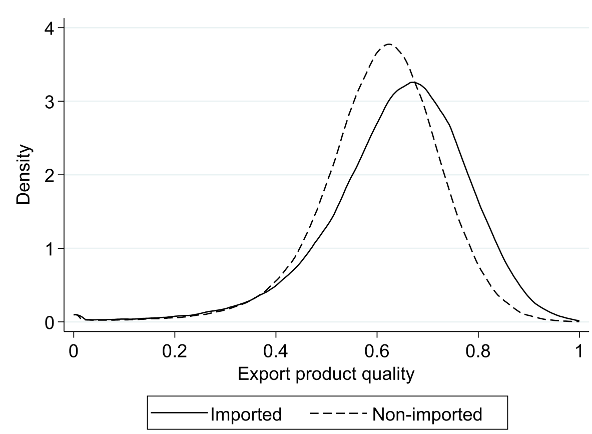

Fig. 2 Distribution of firms' export product quality. Note: In Fig. 2, "Imported" and "Non-imported" refer to the quality distribution of export products of firms that import and do not import digital intermediate products, respectively

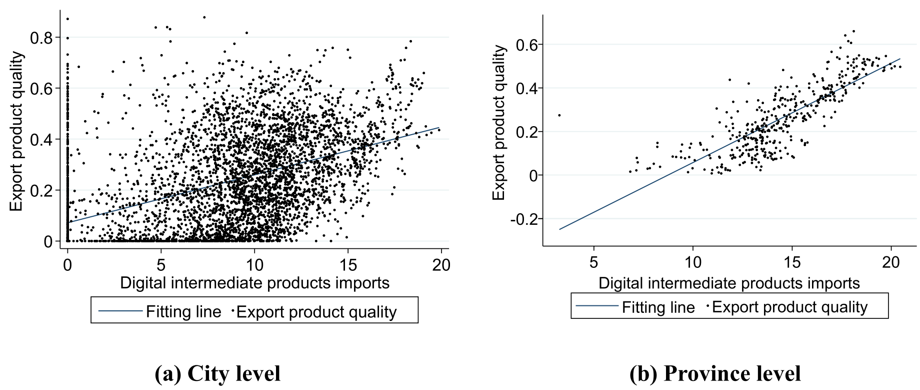

Fig. 3 Two-dimensional scatterplot and fitted line of the main variables. **a** City level. **b** Province level

To initially analyze the relationship between the digital intermediate product imports and the quality of firms' export products, we group the sample firms based on whether they import digital intermediate products. Figure 2 depicts the kernel density distribution of the export product quality of the two types of firms. The results show that the quality of export products of firms that import digital intermediate products is generally higher than that of firms that do not import digital intermediate products. Figure 3 further reports the two-dimensional scatter plot and fitted line of the quality of importing digital intermediate products and export quality at the city level and province level. It can be seen that there is a positive correlation between the digital intermediate product imports and the quality of export products. We preliminarily judge that the import of digital intermediate products can promote the quality of export products of firms.

4 Empirical findings

4.1 Baseline results analysis

We run several regressions specified by Eq. (3). Table 2, column (1)-(4) show that the estimated coefficient of digital intermediate product imports (*lndigi*) is fairly stable across all the columns and significantly positive at the 1% level. Specifically, for every 1% increase in the import of digital intermediate products, the quality of export products will increase by 0.01 units, which is stronger than the quality improvement effect of intermediate product imports (*lnintermediate*) presented in column (5). This can provide preliminary evidence for the validity of hypothesis 1. Further, we regress digital intermediate imports with one-period lag (*lndigi_lag*1) using export product quality to study the long-term effect of adopting the digital intermediate products. The results in column (6) show that the import of digital intermediate products has a long-term improvement effect on the export product quality.[3]

4.2 Control for self-selection bias

The decision of whether a firm import digital intermediate products is not random, as firms with higher export product quality may have a preference for importing digital intermediate products, resulting in estimation bias due to self-selection. Considering this problem, propensity score matching (PSM) is conducted in our study. First, we divide the firms into treatment and control groups based on whether they import digital intermediate products during the sample period. Second, using capital intensity (*lncapint*), firm size (*lnsize*), firm age (*lnage*), capital return (*profit*), and leverage ratio (*leverage*) as matching variables, we conduct the PSM method year-by-year using nearest neighbor matching with a caliper of 0.05, and ratios of 1:1 and 1:3 respectively.[4] Third, we estimate our regression of Eq. (3) based on the matched sample, which are shown in columns (1)-(2) of Table 3. Columns (1)-(2) respectively report the results of 1:1 and 1:3 nearest neighbor propensity score matching, which show that the coefficient of digital intermediate product imports is significantly positive at the 1% level, suggesting that digital intermediate product imports significantly enhances the export quality of firms. This indicates that the validity of hypothesis 1 is not influenced by selection bias.

[3] In fact, according to our regression results, until the second lag period, the import of digital intermediate products still significantly promotes the export product quality.

[4] To ensure the credibility of the matched samples, we conduct a balance test and a common support hypothesis test on the year-by-year samples, and the results all show that the passed. Specifically, the results of the year-by-year balance test show that the standardized deviations of most covariates are effectively reduced after matching, and the absolute values are less than 5%.

Table 2 Impacts of digital intermediate product imports on export product quality

Variable	TQ					
	(1)	(2)	(3)	(4)	(5)	(6)
lndigi	0.0126***	0.0127***	0.0100***	0.0100***		
	(0.0006)	(0.0006)	(0.0006)	(0.0006)		
lnintermediate					0.0036***	
					(0.0001)	
lndigi_lag1						0.0050***
						(0.0006)
lncapint			-0.0051***	-0.0051***	-0.0050***	-0.0049***
			(0.0003)	(0.0003)	(0.0003)	(0.0003)
lnsize			0.0214***	0.0214***	0.0207***	0.0208***
			(0.0006)	(0.0006)	(0.0006)	(0.0007)
lnage			0.0030***	0.0030***	0.0029***	-0.0010
			(0.0009)	(0.0009)	(0.0009)	(0.0013)
subsidy			0.0038***	0.0038***	0.0036***	0.0023***
			(0.0005)	(0.0005)	(0.0005)	(0.0006)
profit			0.0139***	0.0139***	0.0138***	0.0132***
			(0.0013)	(0.0013)	(0.0013)	(0.0015)
leverage			0.0010	0.0010	0.0011	0.0006
			(0.0010)	(0.0010)	(0.0010)	(0.0012)
foreignshare				0.0120***	0.0125***	0.0119***
				(0.0031)	(0.0031)	(0.0035)
lnentrybarrier				-0.0019	-0.0015	-0.0026
				(0.0014)	(0.0014)	(0.0016)
HHI				-0.0115	-0.0121	-0.0069
				(0.0112)	(0.0111)	(0.0131)
agglomeration				-0.0234*	-0.0247**	-0.0305**
				(0.0120)	(0.0118)	(0.0129)
cons	0.6407***	0.6407***	0.4270***	0.4461***	0.4392***	0.4759***
	(0.0003)	(0.0003)	(0.0058)	(0.0158)	(0.0158)	(0.0188)
Year Fixed Effects	YES	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Industry Fixed Effects	NO	YES	YES	YES	YES	YES
City Fixed Effects	NO	YES	YES	YES	YES	YES
Observations	304,260	288,996	287,200	287,200	287,200	206,756
R^2-adjusted	0.6377	0.6327	0.6375	0.6375	0.6386	0.6524

Standard errors, clustered at firm level, are in parentheses. ***Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level. All estimations include a constant term and fixed effects as specified. Table 2 presents the results of the baseline regression analysis. In column (1), only year and firm fixed effects are controlled. In column (2), industry and city fixed effects are further included. To save space, control variables are not presented individually in subsequent regression results

4.3 Endogeneity

"Importing for Export" is a prominent feature of China's foreign trade development (Zhang et al. 2014). Firms may increase their investment in importing digital intermediate products to meet the quality requirements of export deliveries, leading to the problem of reverse causality identification in the research. In addition, there may be omitted variable issues in the specification of the baseline regression equation, which increases the risk of endogeneity. To address these issues, we follow Chen et al. (2017) to construct instrumental variables for digital intermediate product imports from two aspects, importing tariffs and external supplying capacity.

4.3.1 Import tariffs on digital intermediate products

The rationale for using import tariffs on digital intermediate products as an instrumental variable for digital intermediate product imports lies in the fact that changes

Table 3 Endogeneity of treatment effects and self-selection bias in economic academic literature

Variable	*TQ*			
	(1)	(2)	(3)	(4)
	PSM Panel estimation		IV-2SLS	
lndigi	0.0097***	0.0098***	0.0102***	0.0160***
	(0.0007)	(0.0006)	(0.0012)	(0.0011)
cons	0.4030***	0.4266***		
	(0.0280)	(0.0209)		
KP rk LM			1127.179	3370.258
KP rk Wald F			2266.963	5346.704
Control Variables	YES	YES	YES	YES
Fixed Effects	YES	YES	YES	YES
Observations	86,639	164,466	287,200	287,200
R^2-adjusted	0.6446	0.6408	0.0154	0.0142

Standard errors, clustered at firm level, are in parentheses. ***Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level. All estimations include a constant term and fixed effects as specified

in import tariffs can affect firms' import behavior and such changes are exogenous to firms' export behavior, satisfying the requirements of instrument variable construction for relevance and exogeneity. Firm-level import tariffs on digital intermediate products in the current year (TF_{ft}) is detailed in Eq. (8), where θ_{fct}^{g} represents the proportion of digital intermediate product g imported from country c by firm f in year t out of the total import value of digital intermediate products in the base period,[5] $tariff_{ct}^{g}$ represents the tariff rate faced by firm f when importing intermediate goods from country c in year t.[6] The tariff data is at the HS6 product level and sourced from the TRAINS Database of WITS (World Integrated Trade Solution).

$$TF_{ft} = \ln\left(\sum_{g=1}^{N_g}\sum_{c=1}^{N_c}\theta_{fct}^{g} tariff_{ct}^{g}\right) \tag{8}$$

Table 3 reports the regression results using TF_{ft} as the instrumental variable in column (3). The significance tests of the KP rk LM and KP rk Wald F statistics are also presented, and the results reject the hypotheses of "instrumental variable unidentifiability" and "weak instrument" at the 1% significance level, indicating that the instrumental variable chosen in this study is valid. The results show that the coefficient of digital intermediate product imports is significantly positive at the 1% level, supporting the conclusions of the baseline regression analysis.

4.3.2 External supply capacity of digital intermediate products

The external supply capability of digital intermediate products meets the requirements of relevance and exogeneity in constructing variables as import tools for firms. The supply capability of digital intermediate products from source countries affects firms' import behavior, and is exogenous to firms' export behavior after excluding exports to China. External supply capacity of digital intermediate products (WES_{ft}) is detailed in Eq. (9), where $supply_{ct}^{g}$ represents the total value of digital intermediate product g exported by country c to countries except China in year t, and the trade data at the HS6 product level for each country is obtained from the BACI Database of CEPII (Centre détudes prospectives et d'informations internationales).

$$WES_{ft} = \ln\left(\sum_{g=1}^{N_g}\sum_{c=1}^{N_c}\theta_{fct}^{g} supply_{ct}^{g}\right) \tag{9}$$

Table 3, column (4) reports the regression results using WES_{ft} as the instrumental variable, supporting that digital intermediate product imports significantly improves firms' export product quality. This is in line with the hypothesis 1 we proposed earlier. Meanwhile, the results of KP rk LM and KP rk Wald F statistics tests demonstrate the validity of the instrumental variable we chose.

4.4 Robustness tests

This section further corroborates our results by employing new measure of variables, handling outliers, using alternative regression methods, and performing subsample regressions at the firm level, industry level, and city level to test the robustness of our findings.

4.4.1 Alternative measure of variables

Based on the SCDECI and using the method of code conversion, we obtained a list of digital intermediate products in the previous section. In this subsection, following Liu and Sun (2021), we extract 134 keywords related to digital-physical products from the industry code descriptions of the digital product manufacturing sector in the SCDECI.[7] Through web crawling and manual identification with the help of the *`Commodity and Item*

[5] During the sample period, the total import value of digital intermediate products that is not zero for the first time of the firm is regarded as the import value of digital intermediate products in the base period.

[6] We use the WITS AHS weighted average tariff. AHS tariffs are calculated according to the concept of effectively applied tariff, which is defined as the lowest tariff available.

[7] Due to space limitations, the keywords related to digital products are not included here. Interested readers can request them from the authors.

Annotations of Import and Export Tariffs (2020)`, the digital intermediate product imports was recalculated, and the regression results are shown in Table 4 column (1). For export product quality, we set the value of product substitution elasticity σ to 3 when measuring. Following Amiti and Khandelwal (2013), we set the value of σ to 5 and 10 respectively, and the regression results are shown in Table 4 columns (2)-(3). Further, reference to Hallak (2006), we use price weighted by product export value as a proxy for product quality in column (4). The results obtained after substituting the calculation method of variables show no significant difference from our benchmark regression results.

4.4.2 Outlier handling

We conduct a winsorization and a truncation at the 1% level for sample firms' export product quality, and the regression results are shown in Table 4 columns (5)-(6). The results indicate that the processing of sample extreme values do not have a significant impact on our baseline regression results.

4.4.3 Alternative regression method

Considering that the value range of the dependent variable export product quality is limited on both sides between 0 and 1, we use a double-restricted Tobit model for regression. Since adding fixed effects may lead to inconsistent estimates, we only use the Tobit model with random effects, and the regression results are shown in Table 4 column (7). We find that the results of changing the regression method do not significantly differ from the previous results, which means that our benchmark regression results are reliable.

We conduct sample regression analyses separately at the firm level, industry level, and city level in the following subsections to test the robustness.

4.4.4 Firm level differentiating between firm ownership types

We categorize firms into state-owned, private, and foreign-owned based on the proportion of paid-in capital (≥ 50%), and the regression results are in Table 5 columns (1)-(3). The results indicate that the coefficient of digital intermediate product imports is significantly positive at the 1% level for private and foreign-owned firms, while the significance level of the coefficient for state-owned firms is only 10%. Possible reasons for this phenomenon are twofold. On the one hand, state-owned firms have relatively stable production and operation modes with lower personnel turnover rate (Cai and Qi 2021), and the effect of digital intermediate product imports on improving productivity through optimizing the allocation of capital and labor resources is relatively small. On the other hand, state-owned firms receive greater government subsidies and policy support, face less market competition pressure, and lack the impetus for technological progress compared to private and foreign-owned firms (Hong et al. 2022).

4.4.5 Firm level differentiating between trade types

We categorize the sample firms into three groups, according to the trade mode: purely general trade, purely processing trade, and mixed trade. The regression results are in Table 5 columns (4)-(6), show that all coefficients

Table 4 Robustness check regression results

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	TQ	*TQσ5*	*TQσ10*	*Price*	*TQ*		
	Replacing Indicators				Extreme Value Handling		Bivariate Tobit
lndigi		0.0100***	0.0100***	0.0717***	0.0096***	0.0090***	0.0097***
		(0.0006)	(0.0006)	(0.0073)	(0.0005)	(0.0005)	(0.0003)
lndigikeyword	0.0090***						
	(0.0006)						
cons	0.4436***	0.4461***	0.4461***	-3.4119***	0.4523***	0.4636***	0.7378***
	(0.0158)	(0.0158)	(0.0158)	(0.1631)	(0.0147)	(0.0137)	(0.0056)
Control Variables	YES	YES	YES	YES	YES	YES	YES
Fixed Effects	YES	YES	YES	YES	YES	YES	NO
Observations	287,200	287,200	287,200	512,745	287,200	281,058	325,040
R^2-adjusted	0.6373	0.6375	0.6375	0.8749	0.6533	0.6530	

Standard errors, clustered at firm level, are in parentheses. ***Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level. All estimations include a constant term and fixed effects as specified. This is the inclusion of multiple robustness tests, with column (1) remeasuring the digital intermediate product imports, columns (2)-(3) remeasuring the export product quality, columns (4)-(5) treating extreme values, and column (6) changing the regression method

Table 5 Regression results of subsample at the firm level

Variable	*TQ*					
	(1)	(2)	(3)	(4)	(5)	(6)
	State-owned Firms	Private Firms	Foreign-funded Firms	General Trading Firms	Processing Trade Firms	Mixed Trade Firms
Indigi	0.0123*	0.0091***	0.0090***	0.0076***	0.0158***	0.0083***
	(0.0074)	(0.0010)	(0.0008)	(0.0015)	(0.0021)	(0.0007)
cons	0.3088	0.4478***	0.4721***	0.4444***	0.4020***	0.4745***
	(0.2850)	(0.0221)	(0.0263)	(0.0244)	(0.0753)	(0.0237)
Control Variables	YES	YES	YES	YES	YES	YES
Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	3484	139,735	100,512	136,746	12,142	123,044
R^2-adjusted	0.4879	0.6094	0.6480	0.6058	0.7355	0.6475

Standard errors, clustered at firm level, are in parentheses. ***Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level. All estimations include a constant term and fixed effects as specified

of digital intermediate product imports are significantly positive at the 1% level, indicating that digital intermediate product imports significantly promote the export product quality for firms in different trade modes.

4.4.6 Industry level

Industries with different technological characteristics exhibit differences in the intensity of digital intermediate product imports and the distribution gradient of product quality. For example, digitalization, patent-intensive, and high-tech industry tend to use more digital components in their production and manufacturing processes. Moreover, due to the widespread use of automated machinery and equipment in these industries, the differences in product quality among firms are relatively small. To test whether there are heterogeneous effects of digital intermediate product imports at the industry level, we conduct subsample regressions in three ways: First, the sample firms are divided into digital industrialization industry and industrial digitalization industry according to the SCDECI, and the regression results are in Table 6 columns (1)-(2); Second, the sample firms are divided into patent-intensive and non-patent-intensive industry according to the `*Classification of Patent-Intensive Industries (2019)*`, and the regression results are in Table 6 columns (3)-(4); Third, the sample firms are divided into high-tech and non-high-tech industry according to the `*Classification of High-Tech Industries (Manufacturing) (2019)*`, and the regression results are in Table 6 columns (5)-(6). The results show the coefficients of digital intermediate product imports, which are significantly positive at the 1% level for all subsamples, indicating that digital intermediate product imports significantly promote

Table 6 Regression results of subsample at the industry level

Variable	*TQ*					
	(1)	(2)	(3)	(4)	(5)	(6)
	Digital Industrialization Industry	Digitalization of Industrial Sector	Patent-Intensive Industry	Non-Patent-Intensive Industry	High-Tech Industry	Non-High-Tech Industry
Indigi	0.0107***	0.0096***	0.0107***	0.0101***	0.0101***	0.0098***
	(0.0010)	(0.0008)	(0.0009)	(0.0008)	(0.0009)	(0.0008)
cons	0.2883***	0.4421***	0.3805***	0.4599***	0.3165***	0.4549***
	(0.0536)	(0.0199)	(0.0360)	(0.0214)	(0.0449)	(0.0199)
Control Variables	YES	YES	YES	YES	YES	YES
Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	25,436	250,552	64,196	207,624	28,797	246,112
R^2-adjusted	0.6658	0.6349	0.6499	0.6269	0.6590	0.6342

Standard errors, clustered at firm level, are in parentheses. ***Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level. All estimations include a constant term and fixed effects as specified

Table 7 Regression results of subsample at the city-level

Variable	*TQ*					
	(1)	(2)	(3)	(4)	(5)	(6)
	Central City	Non-Central City	Eastern City	Central-Western City	High Innovation Level City	Medium–Low Innovation Level City
lndigi	0.0088***	0.0107***	0.0101***	0.0075**	0.0085***	0.0105***
	(0.0011)	(0.0007)	(0.0006)	(0.0035)	(0.0010)	(0.0008)
cons	0.4541***	0.4463***	0.4505***	0.4397***	0.4676***	0.4662***
	(0.0301)	(0.0186)	(0.0160)	(0.0740)	(0.0295)	(0.0204)
Control Variables	YES	YES	YES	YES	YES	YES
Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	77,561	209,606	269,138	18,039	82,152	162,768
R^2-adjusted	0.6431	0.6361	0.6401	0.5899	0.6507	0.6441

Standard errors, clustered at firm level, are in parentheses. ***Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level. All estimations include a constant term and fixed effects as specified

export product quality in industries with different technological characteristics.

4.4.7 City-level

The impact of digital intermediate product imports on export product quality may vary due to heterogeneity in city-level administrative hierarchy, geographic location, and technological innovation capability. We first categorize firms located in prefecture-level cities, directly administered cities, and provincial capitals as central city group, and the rest as non-central city group. The subsample regression results are in Table 7 columns (1)-(2), indicating that digital intermediate product imports significantly promote the export product quality for both central city group and non-central city group at the 1% significance level. Second, firms are divided into eastern city group and central-western city group based on their geographic locations. The subsample regression results are in Table 7 columns (3)-(4), indicating that the effect of digital intermediate product imports on quality improvement is more pronounced in the eastern city group compared to the central-western city group. This may be explained by the higher level of digital economic development, relatively well-developed digital infrastructure, and abundant resources such as digital talents and technologies in the eastern region (Hong et al. 2022), which enable firms to better leverage imported digital intermediate products. Third, according to the Chinese City Innovation Index calculated by Kou and Liu (2017),[8] the top one-third of cities are classified as high innovation level city group, while the rest are classified as medium–low innovation level city group. The subsample regression results are in Table 6 columns (5)-(6). The results indicate that digital intermediate product imports significantly promote the export product quality for both high innovation level city group and medium–low innovation level city group at the 1% significance level.

In summary, after addressing sample selection bias, controlling endogeneity issues, conducting robustness tests that include remeasuring core variables, handling outliers, changing regression methods, and performing subsample regressions, digital intermediate product imports still significantly promotes the upgrading of product quality in exporting firms. This strongly confirms our hypothesis 1.

5 The underlying mechanisms

5.1 Productivity channel

Based on the endogenous determination model of firm product quality proposed by Hallak and Sivadasan (2009), productivity differences are one of the main reasons for the heterogeneity in export product quality of firms. Following Levinsohn and Petrin (2003), we measure productivity using total factor productivity (*TFP*), and examine whether the digital intermediate product imports affects firms' export product quality through productivity.

We start with examining the causal relationship between the digital intermediate product imports and the productivity. As shown in Table 8 column (1), the impact of digital intermediate product imports on productivity is significantly positive. We further employ the PSM-panel estimation method used in previous sections and conduct baseline regression with 1:1 and 1:3 nearest neighbor propensity score matching in

[8] Kou and Liu (2017) calculated the innovation index for 338 cities from 2001 to 2016. Considering the sample period of this study, only the data of city innovation index from 2001 to 2013 are selected.

Table 8 Digital intermediate product imports and productivity

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	TFP					***TQ***
	Panel Estimation	**PSM-Panel Estimation**		**IV-2SLS**		**Panel Estimation**
lndigi	0.0483***	0.0401***	0.0444***	0.0537***	0.0485***	
	(0.0037)	(0.0049)	(0.0039)	(0.0077)	(0.0075)	
TFP						0.0066***
						(0.0003)
cons	1.8405***	1.2421***	1.4729***			0.4134***
	(0.1085)	(0.1918)	(0.1397)			(0.0161)
KP rk LM				1109.646	3331.860	
KP rk Wald F				2256.368	5284.109	
Control Variables	YES	YES	YES	YES	YES	YES
Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	282,376	85,176	161,809	282,376	282,376	282,376
R^2-adjusted	0.6889	0.6855	0.6924	0.1038	0.1039	0.6365

Standard errors, clustered at firm level, are in parentheses. ***Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level. All estimations include a constant term and fixed effects as specified

Table 8 columns (2)-(3) to address potential sample selection bias. The results show that digital intermediate product imports still has a significant promoting effect on productivity. To address potential endogeneity issues caused by reverse causality and omitted variable bias, we use import tariffs and external supply capacity of digital intermediate products as instrumental variables for digital intermediate product imports, and conduct IV-2SLS regressions in Table 8 columns (4)-(5). The results show that even after considering endogeneity issues, digital intermediate product imports still significantly enhances firms' productivity.

In the second place, we examine the correlation between productivity and export product quality. According to the results in Table 8 column (6), there is a significant positive correlation between productivity and export product quality, providing evidence for the conclusion that productivity is a key influencing factor for export product quality. Combining the regression results in Table 8, we argue that there is a rational mechanism for digital intermediate product imports to promote the export product quality through productivity.

Further, we examine specific aspects of the impact of digital intermediate product imports on productivity. Considering that digital intermediate product imports mainly improve firms' productivity through capital factors such as machinery and labor factors, we decompose total factor productivity into capital output efficiency (*Keff*) and labor output efficiency (*Leff*), and examine whether digital intermediate product imports have positive effects on them. The construction of *Keff* and *Leff* refers to Zhang and Deng (2020):

$$Keff_{ijft} = \ln\left(\eta_j \frac{\sigma - 1}{\sigma} \frac{P_{jft} Y_{jft}}{RK_{jft}}\right), Leff_{ijft} = \ln\left(\mu_j \frac{\sigma - 1}{\sigma} \frac{P_{jft} Y_{jft}}{\omega L_{jft}}\right) \tag{10}$$

where i,j,f,t represent city i, industry j, firm f and year t respectively.η_j,μ_j represent the capital elasticity and labor elasticity respectively, satisfying $\mu_j = 1 - \eta_j$, and using the fixed effect method to calculate.σ is the product substitution elasticity, set at 3.$P_{jft} Y_{jft}$ denotes the actual output, measured by the value added of the firm's industrial production. The price of capital input,R, is set at 0.1, and K_{jft} represents the net fixed assets. The price of labor input,ω, is set at 1, and L_{jft} represents the total labor compensation. As indicated by Eq. (10), $Keff_{ijft}$ and $Leff_{ijft}$ represent the ratio of marginal returns to marginal costs of input factors for firms, the higher the value of $Keff_{ijft}$ and $Leff_{ijft}$, the higher the capital output efficiency and labor output efficiency.

The results in Table 9 columns (1)-(2) show that the coefficients of digital intermediate product imports are statistically significant at the 1% level, indicating that digital intermediate product imports can promote the capital output efficiency and labor output efficiency for firms. Combined with the results in Table 9 column (3), we conclude that digital intermediate product imports can enhance both capital output efficiency and labor output efficiency, thereby improving firms' productivity.

5.2 Quality production capacity channel

Quality production capacity is the another channel. This subsection, we use the number of patent applications processed by adding 1 to the logarithm of the firm in the current year as a measure of the quality production

Table 9 Digital intermediate product imports, productivity, and export product quality

Variable	(1) *Keff*	(2) *Leff*	(3) *TFP*
lndigi	0.0325***	0.0153***	
	(0.0040)	(0.0040)	
Keff			0.8708***
			(0.0011)
Leff			0.0777***
			(0.0010)
cons	1.8692***	-0.8901***	0.3246***
	(0.1145)	(0.1148)	(0.0243)
Control Variables	YES	YES	YES
Fixed Effects	YES	YES	YES
Observations	264,746	264,845	264,746
R^2-adjusted	0.7873	0.6201	0.9872

Standard errors, clustered at firm level, are in parentheses. ***Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level. All estimations include a constant term and fixed effects as specified

capacity (*ability*) and examine whether digital intermediate product imports promote export product quality by enhancing quality production capacity. The rationale for using patent applications as a proxy for quality production capacity is that a firm's ability to produce high-quality products is often linked to its own innovation capability and technological level. The stronger a firm's innnovation capability and technological level, the more patents it is likely to generate. The patent data used in this study is obtained from the China Patent Database.

Similar to the logic for testing the mechanism of productivity, we conduct the following analysis: Firstly, the results in Table 10 column (1) show that digital intermediate product imports have a significant positive impact on quality production capacity. Secondly, the results in Table 10 columns (2)-(5) show that even after conducting benchmark regression with 1:1 and 1:3 caliper nearest neighbor propensity score matching respectively, and using import tariffs and external supply capacity of digital intermediate products as instrumental variables, digital intermediate product imports still significantly improves firms' quality production capacity. Finally, the results in Table 10 column (6) support the inference by Hallak and Sivadasan (2009) that quality production capacity is a key determinant of firms' export product quality. The results in Table 10 demonstrate that the mechanism by which the digital intermediate product imports promotes the export product quality through the improvement of quality production capacity does exist.

In summary, we verify that digital intermediate product imports can significantly improve firms' productivity and quality production capacity, and promote the export product quality under the mechanism of Hallak and Sivadasan (2009), which strongly validates our hypothesis 2.

6 Does the characteristics of digital intermediate product imports matter?

In the previous section, we conclude that increasing the import scale of digital intermediate products has a positive impact on the firms' export product quality. Meanwhile, the impact of other characteristics of digital intermediate product imports also deserves attention, such as technological content, diversification and

Table 10 Digital intermediate product imports, quality production capacity, and export product quality

Variable	(1) *ability*	(2)	(3)	(4)	(5)	(6) *TQ*
	Panel Estimation	PSM- Panel Estimation		IV-2SLS		Panel Estimation
lndigi	0.0230***	0.0114**	0.0186***	0.0394***	0.0407***	
	(0.0043)	(0.0052)	(0.0043)	(0.0098)	(0.0087)	
ability						0.0036***
						(0.0004)
cons	0.5592***	0.9912***	0.9629***			0.4336***
	(0.1263)	(0.2120)	(0.1622)			(0.0163)
KP rk LM				1059.418	3158.801	
KP rk Wald F				2219.576	5026.194	
Control Variables	YES	YES	YES	YES	YES	YES
Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	272,936	80,859	154,137	272,936	272,936	272,936
R^2-adjusted	0.4674	0.4813	0.4779	0.0035	0.0034	0.6363

Standard errors, clustered at firm level, are in parentheses. ***Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level. All estimations include a constant term and fixed effects as specified quality. Halpern et al. (2015) deem that intermediate product imports will improve the production capacity of corresponding intermediate products of firms through channels such as technology spillover effects and learning effects, thereby promoting the export product quality. Song et al. (2019) believe that the diversification of intermediate product imports improves the export product quality by reducing the marginal cost and improving the technology assimilation capacity of firms. Xu and Mao (2018), Bas and Vanessa (2015) pointed out that export product quality improves more from importing higher quality intermediate products than intermediate products with lower quality. Therefore, this section rechecks the impact of the technological content, diversification level, and quality of digital intermediate product imports on the firms' export product quality.

6.1 Technological content of digital intermediate product imports

Technical content emphasizes the technical characteristics of products and reflects the differences in technical levels across products (Shi and Shao 2014). High-tech digital intermediate products contain cutting-edge digital product manufacturing processes and production technologies. By learning and assimilating foreign advanced production technology contained in high-tech imported digital intermediate products, firms may improve the quality of export products.Following Wu et al. (2017), we measure the technical content of the firm's digital intermediate product imports ($lndigitech_{ft}$) based on Eq. (11):

$$lndigistech_{ft} = \ln\left(\sum_{g=1}^{N_g}\sum_{c=1}^{N_c}\frac{imp_{fct}^{g}}{GDP_{ct}}S_{ct}^{d}\right) \tag{11}$$

where imp_{fct}^{g} represents the digital intermediate product imports of firm f in year t,GDP_{ct} represents the gross domestic product (GDP) of country c as the source of imports in year t.S_{ct}^{d} represents the domestic RandD stock of country c in year t, calculated using perpetual inventory method as $S_{ct}^{d} = (1-\delta)S_{c,t-1}^{d} + RD_{ct}$, where δ is assumed to be 0.05, and RD_{ct} represents the RandD expenditure of country c in year t. The data on GDP and RandD expenditure for each country are obtained from the World Bank Database.

We examine the impact of technological content of digital intermediate product imports on export product quality by controlling for the interaction term of digital intermediate product imports and technical content ($lndigi \times lndigitech$) in Eq. (3). Table 11 column (1) shows that the coefficient of the interaction term $lndigi \times lndigitech$ is small and not statistically significant, indicating that the import of high technological content digital intermediate products does not further promote the improvement of firm's export product quality. One possible reason is that although high-tech digital intermediate products have higher technological spillover value, they also increase the learning difficulty for firms (Liu 2021). Due to the constraints of firms' own knowledge stock, experience reserves, and shortage of high-end labor, the quality upgrading effect of importing high-tech digital intermediate products is not significant.

Table 11 Results for different characteristics of digital intermediate product imports

Variable	TQ		
	(1)	(2)	(3)
lndigi	0.0098***	0.0074***	0.0091***
	(0.0007)	(0.0009)	(0.0007)
lndigi × lndigitech	0.0001		
	(0.0002)		
lndigi × lndiginumber		0.0011***	
		(0.0003)	
lndigi × digiquality			0.0024**
			(0.0010)
cons	0.4463***	0.4481***	0.4468***
	(0.0158)	(0.0158)	(0.0158)
Control Variables	YES	YES	YES
Fixed Effects	YES	YES	YES
Observations	287,200	287,200	287,200
R^2-adjusted	0.6375	0.6375	0.6375

Standard errors, clustered at firm level, are in parentheses. ***Significant at the 1% level; **Significant at the 5% level; *Significant at the 10% level. All estimations include a constant term and fixed effects as specified

6.2 Diversification of digital intermediate product imports

The diversification of digital intermediate product imports refers to the diversification of the types and sources of digital intermediate products imported by firms. The motives of firms to diversify intermediate product imports include obtaining a lower-cost input mix of intermediate products to increase productivity (Halpern et al. 2015), searching for high-quality intermediate products (Cadot et al. 2014), etc. To further verify whether the diversification of digital intermediate product imports can promote export product quality, following Bas and Vanessa (2011), we measure diversification of digital intermediate product imports ($lndiginumber$) by the number of trade relations of digital intermediate products imported by firms. Trade relations are defined as country-product pairs, that is, digital intermediate products with the same 6-digit HS code from different countries are recorded as different product categories.

Table 11 column (2) shows that the coefficient of the interaction term of digital intermediate product imports and diversification ($lndigi \times lndiginumber$) is significantly positive, indicating that firms with more diversified digital intermediate product imports achieve greater improvement in export product quality. This result maybe attribute to that diversified digital intermediate product imports has cost-saving effects (Xu et al. 2017). Goldberg et al. (2010) pointed out that importing new types of intermediate products reduces firms' import price index of intermediate products by 4.7%. Therefore, the more diverse the types of digital intermediate products imported by firms, the lower the relative cost of payment, and firms can invest more funds to support the upgrading of their own product quality.

6.3 Quality of digital intermediate product imports

Quality refers to all comprehensive characteristics that cause changes in consumer utility levels under the condition of constant product quantity (Gervin 1984), emphasizing vertical differences within products. This means that the higher the quality of digital intermediate product imports, the greater the utility obtained by firms. We are interested in whether improving the quality of digital intermediate product imports can further improve the quality of firms' export products. Following Shi and Zeng (2015), we measure the quality of digital intermediate product imports (*digiquality*), using the demand information regression method based on Eq. (12):

$$lnq_{fct}^{g} = \gamma_t - \sigma lnp_{fct}^{g} + lnGDP_{ct} + \varepsilon_{fct}^{g} \tag{12}$$

where γ_t is the time dummy variable used to control product consumption in the Chinese market.

$lnGDP_{ct}$ denotes the logarithm of the GDP of import source country c in year t, which is used to control the impact of product horizontal differentiation. Furthermore, to address the endogeneity problem caused by the regression of demand on price, we use the average price of product g imported by firm f from other countries in year t as an instrumental variable. Subsequent data processing and standardization, product quality weighting at the firm level refer to the measurement of export product quality above, and will not be repeated here.

Table 11 column (3) shows that the coefficient of the interaction term of digital intermediate product imports and quality ($lndigi \times digiquality$) is significantly positive, indicating that the higher the quality of digital intermediate product imports, the higher the quality of export product quality. The possible explanation is that the import of high-quality digital intermediate products strengthens the quality transfer effect in the input–output process of firms, and then promotes the export product quality by improving the quality production capacity. In addition, the import of high-quality digital intermediate products provides firms with an opportunity to access foreign cutting-edge production technologies. By learning and assimilating imported high-quality digital intermediate products, firms can improve their own technical level, thereby improving the export product quality (Zheng et al. 2017).

7 Conclusion and policy suggestions

Based on matched data of Chinese Manufacturing Firms Database and the China Customs Trade Database from 2000 to 2013, this study empirically examines the impact and mechanism of digital intermediate product imports on the export product quality. The findings are as follows: (1) Digital intermediate product imports can promote the export product quality of firms, and this result remains robust after a series of robustness tests and endogeneity treatments. (2) Mechanism test results indicate that digital intermediate product imports promotes the export product quality by enhancing productivity and quality production capability. (3) Digital intermediate product imports has a significant positive effect on the export product quality for different firms, industries, and cities. (4) The higher quality and the more diversified types of digital intermediate product imports lead to greater improvement in the export product quality, while the higher technological content does not.

Our findings have important implications for promoting manufacturing industry upgrading in the digital era: First, digital intermediate product imports contributes to the improvement of export product quality for manufacturing firms in developing countries. The export optimization path based on "expanding the import of digital intermediate products" is an important path for developing countries to integrate in global economy and build an international cycle with equal emphasis on quality and efficiency. Second, the impact of digital intermediate product imports on the export product quality varies with different characteristics. The government should guide firms to optimize the import structure of digital intermediate products, encourage the import of high-quality and diversified digital intermediate products, and balance the gap between imported digital intermediate products and its own technical level. To address the issue of insignificant spillover effects from digital intermediate product imports with higher technological content, the government should guide firms to strengthen their technology absorption and transformation capabilities, increase investment in research and development, and narrow the gap between firms and the international technological frontier in the same industry.

Authors' contributions

Ren Wanwan is responsible for the proposal of the article idea and the overall planning. Material preparation, data collection and analysis was performed by Lin Tianhan. The first to final draft of the manuscript was written by Lin Tianhan and Hao Yuqian. All authors read and approved the final manuscript.

Funding

This study is partially funded by "'Internet + Industrial Clusters' and the High-end Climbing of the Global Value Chain: Theoretical Model and Chinese Experience" (71903175) and "Domestic Market Size, 'Conjugate Circulation' Embedding Selection and Binary Upgrade Path Model: Theory and Identification" (72003174), which is supported by National Natural Science Foundation of China Youth Project.

1. National Natural Science Foundation of China Youth Project (71903175) "Internet + Industrial Clusters' and the High-end Climbing of the Global Value Chain: Theoretical Model and Chinese Experience".

2. National Natural Science Foundation of China Youth Project (72003174) "Domestic Market Size, 'Conjugate Circulation' Embedding Selection and Binary Upgrade Path Model: Theory and Identification".

3. Zhejiang National Natural Science Foundation Youth Project (LQ19G030005) "Research on the High-end Climbing Path of China's Global Value Chain from the Perspective of Industrial Clusters".

4. Supported by the Project of China (Hangzhou) Cross-border E-commerce College (No.2021KXYJ02) "Research on the Path of Virtual Transformation of Industrial Clusters to Boost the High-end Climbing of the Manufacturing Global Value Chain".

5. A Project Supported by Scientific Research Fund of Zhejiang Provincial Education Department (Y202250328) "Research on the Intrinsic Mechanism and Path of Digital Intermediate Product Import Enabling the Quality Upgrading of Export Product".

6. A Project Supported by Postgraduate Scientific Research and Innovation Fund of Zhejiang Gongshang University "Digital Intermediate Goods Import Quality and Enterprise Global Value Chain High-end Climbing".

Declarations

Ethics approval and consent to participate

The work has not been considered to publish elsewhere, in whole or in part. All authors have approved to this submission to your esteemed journal, and the ranking of contributions in the paper. Its publication is also approved tacitly by the responsible authorities where the work was carried out. We agree that if accepted, the paper will not be published elsewhere in the same form, in English or in any other language, without the written consent of the Publisher.

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

Received: 19 October 2023 Revised: 26 February 2024 Accepted: 3 March 2024
Published online: 08 April 2024

References

Amiti, M., and A.K. Khandelwal. 2013. Import competition and quality upgrading. *Review of Economics and Statistics* 95 (2): 476–490. https://doi.org/10.1162/REST_a_00271.

Ardito, L., D. D'Adda, and A.M. Petruzzelli. 2017. Mapping innovation dynamics in the internet of things domain: evidence from patent analysis. *Technological Forecasting and Social Change* 136: 317–330. https://doi.org/10.1016/j.techfore.2017.04.022.

Bas, M., and S.K. Vanessa. 2011. Does importing more inputs raise exports? Firm level evidence from France. *CEPII Working Paper* No.2011–15.

Bas, M., and V. Strauss-Kahn. 2014. Does importing more inputs raise exports? Firm-level evidence from France. *Review of World Economics* 150 (2): 241–275. https://doi.org/10.1007/s10290-013-0175-0.

Bas, M., and V. Strauss-Kahn. 2015. Input-trade liberalization, export prices and quality upgrading. *Journal of International Economics* 95 (2): 250–262. https://doi.org/10.1016/j.jinteco.2014.12.005.

Bastos, P., Artuc, E., and B. Rijkers. 2020. DP14487 Robots, tasks, and trade. *CEPR Press Discussion Paper* No. 14487. https://cepr.org/publications/dp14487

Cadot, O., C. Carrere, and V. Strauss-Kahn. 2014. OECD Imports: Diversification of Suppliers and Quality Search. *Review of World Economics* 150 (1): 1–24. https://doi.org/10.1007/s10290-013-0172-3.

Cai, Z.K., and J.H. Qi. 2021. Does the adoption of industrial robots upgrade the export product qualit—evidence from Chinese manufacturing enterprises. *Journal of International Trade* 10: 17–33. https://doi.org/10.13510/j.cnki.jit.2021.10.002.

Chen, Z., J. Zhang, and W. Zheng. 2017. Import and innovation: Evidence from Chinese firms. *European Economic Review* 94: 205–220. https://doi.org/10.1016/j.euroecorev.2017.02.008.

Feng, L., Z.Y. Li, and D.L. Swenson. 2016. The connection between imported intermediate inputs and exports: Evidence from Chinese firms. *Journal of International Economics* 101: 86–101. https://doi.org/10.1016/j.jinteco.2016.03.004.

Gao, J.F., and B. Wang. 2020. Does digital technology promote China's global value chain position. *International Economics and Trade Research* 36 (11): 35–51. https://doi.org/10.13687/j.cnki.gjjmts.2020.11.003.

Goldberg, P.K., A.K. Khandelwal, N. Pavcnik, et al. 2010. Imported intermediate inputs and domestic product growth: Evidence from India. *Quarterly Journal of Economics* 125 (4): 1727–1767. https://doi.org/10.1162/qjec.2010.125.4.1727.

Hallak, J.C., and Sivadasan, J. 2009. Firms' exporting behavior under quality constraints. *NBER Working Paper* No.14928. https://doi.org/10.3386/w14928

Hallak, J.C. 2006. Product quality and the direction of trade. *Journal of International Economics* 238–265. https://doi.org/10.1016/j.jinteco.2005.04.001

Halpern, L., M. Koren, and A. Szeidl. 2015. Imported inputs and productivity. *American Economic Review* 105 (12): 3660–3703. https://doi.org/10.1257/aer.20150443.

Hausmann, R., and D. Rodrik. 2003. Economic development as self-discovery. *Journal of Development Economics* 72 (2): 603–633. https://doi.org/10.1016/S0304-3878(03)00124-X.

Hong, J.J., M.C. Jiang, and C.Y. Zhang. 2022. Digital transformation, innovation and the improvement of enterprises' export quality. *Journal of International Trade* 3: 1–15. https://doi.org/10.13510/j.cnki.jit.2022.03.001.

Huang, X.H., and H.D. Wang. 2022. Imports of digital products, knowledge stock and digital innovation of enterprises. *Journal of Zhejiang University (humanities and Social Sciences)* 52 (02): 28–43. https://doi.org/10.3785/j.issn.1008-942X.CN33-6000/C.2021.11.174.

Kou, Z.L., and Liu, X.Y. 2017. China urban and industrial innovation report 2017. *Fudan University Industrial Development Research Center*.

Kugler, M., and E. Verhoogen. 2012. Prices, plant size, and product quality. *Review of Economic Studies* 79 (1): 307–339. https://doi.org/10.1093/restud/rdr021.

Liu, H. 2021. Imported technology content of intermediate goods and domestic value-added rate of manufacturing products. *Journal of International Trade* 6: 96–109. https://doi.org/10.13510/j.cnki.jit.2021.06.007.

Liu, J.Q., and P.Y. Sun. 2021. How does digital product import effectively promote enterprise innovation—based on an empirical analysis of micro enterprises in China. *Journal of International Trade* 8: 38–53. https://doi.org/10.13510/j.cnki.jit.2021.08.003.

Liu, H.Y., L.T. Lin, and L. Gao. 2017. Quality upgrade of imported intermediate goods and export products: Evidence from micro-enterprises. *Journal of International Trade* 2: 39–49. https://doi.org/10.13510/j.cnki.jit.2017.02.004.

Loebbecke, C. 2003. Digital goods: an economic perspective. *Encyclopedia of Information Systems* 635-647https://doi.org/10.1016/B0-12-227240-4/00043-5

Lu, T., and R. Li. 2022. Digital transformation of manufacturing enterprises: The perspective of data elements empowering traditional elements. *Study and Exploration* 9: 108–117. https://doi.org/10.3969/j.issn.1002-462X.2022.09.016.

Ma, S.Z., and G.J. Wu. 2016. Internediate goods imports, trade types and the quality of export products. *Journal of Quantitative and Technological Economics* 33 (11): 77–93. https://doi.org/10.13653/j.cnki.jqte.2016.11.005.

Porter, M.E., and J.E. Heppelmann. 2015. How smart, connected products are transforming competition. *Harvard Business Review* 93: 1–37 (https://api.semanticscholar.org/CorpusID:167014495).
Shi, B.Z., and W.B. Shao. 2014. Calculation of export product quality of Chinese enterprises and its determinants—a microscopic perspective on cultivating new advantages in export competition. *Journal of Management World* 9: 90–106. https://doi.org/10.19744/j.cnki.11-1235/f.2014.09.009.
Shi, B.Z., and X.F. Zeng. 2015. Quality estimation and facts of imported products by Chinese enterprises. *Journal of World Economy* 38 (03): 57–77. https://doi.org/10.19985/j.cnki.cassjwe.2015.03.004.
Song, Y.G., Y.G. Wu, G.Y. Deng, and P.F. Deng. 2021. Intermediate imports, institutional environment, and export product quality upgrading: Evidence from Chinese micro-level firms. *Emerging Markets Finance and Trade* 57 (2): 400–426. https://doi.org/10.1080/1540496X.2019.1668765.
Wu, Y.G., Y.G. Song, and G.Y. Deng. 2017. Institutional environment, OFDI, and TFP growth: Evidence from China. *Emerging Markets Finance and Trade* 53 (9): 2020–2038. https://doi.org/10.1080/1540496X.2017.1283612.
Xu, J.Y., and Q.L. Mao. 2018. On the relationship between intermediate input imports and export quality in China. *Economics of Transportation* 26 (3): 429–467. https://doi.org/10.1111/ecot.12155.
Yoo, Y., O. Henfridsson, and K. Lyytinen. 2010. Research commentary-the new organizing logic of digital innovation:An agenda for information systems research. *Information Systems Research* 21 (4): 724–735. https://doi.org/10.1287/isre.1100.0322.
Yu, H., L. Yao, and H.L. He. 2022. How does digital product import affect the export technology complexity of Chinese enterprises? *Journal of International Trade* 3: 35–50. https://doi.org/10.13510/j.cnki.jit.2022.03.002.
Zhang, T.H., and Y.M. Deng. 2020. Development zone, resource allocation and macroeconomic efficiency—empirical research based on Chinese industrial enterprises. *China Economic Quarterly* 19 (04): 1237–1266. https://doi.org/10.13821/j.cnki.ceq.2020.03.05.
Zhang, J., Y.C. Liu, and W.P. Zheng. 2013. Why does export inhibit Chinese enterprises' value-added ratio?—an investigation based on government's behavior. *Journal of Management World* 6: 12–27+187. https://doi.org/10.19744/j.cnki.11-1235/f.2013.06.002.
Zhang, J., W.P. Zheng, and Z.Y. Chen. 2014. Do imports lead to exports: a microscopic interpretation of China's export miracle. *Journal of World Economy* 37 (06): 3–26. https://doi.org/10.19985/j.cnki.cassjwe.2014.06.002.
Zhang, H.S., Liu, Q.Q., and Wei, Y.L. 2023. Digital product imports and export product quality: Firm-level evidence from China. *China Economic Review* 79. https://doi.org/10.1016/j.chieco.2023.101981
Zheng, Y.L., Y. Wang, and J. Guo. 2017. Effect of quality of imported intermediate product on firm productivity: evidence from different levels. *Journal of International Trade* 6: 50–60. https://doi.org/10.13510/j.cnki.jit.2017.06.005.
Zhu, Z.J., Y.M. Yuan, and J.J. Jiao. 2022. Industrial automation and manufacturing innovation behavior. *China Industrial Economics* 412 (07): 84–102. https://doi.org/10.19581/j.cnki.ciejournal.2022.07.019.

Publisher's Note