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Research article

The impact of digital economy on the export competitiveness of China's manufacturing industry

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Abstract: The digital economy is an important driving force for the high-quality development of the manufacturing industry. This paper uses 2013–2019 manufacturing panel data to empirically test the impact of digital economic growth on China's manufacturing export competitiveness. The results show that, first, the degree of integration of manufacturing and digital economy in the eastern region is higher than that in the central and western regions. Second, the development of the digital economy has indeed had a significant positive impact on the export competitiveness of China's manufacturing industry. Third, the digital economy has different impacts on the export competitiveness of manufacturing industries in different industries and regions. Based on the findings, some suggestions are made to further enhance the export competitiveness of China's manufacturing industry, such as paying attention to the development of digital infrastructure, optimizing the mode of integration of the manufacturing sector and the digital economy, and enhancing international collaboration in digital technology innovation.

Keywords: digital economy; export competitiveness; manufacturing industry; technical complexity; principal component analysis; entropy method

1. Introduction

The deep integration of the digital economy and the real economy is an important cornerstone for China's economy to shift to the stage of high-quality development and build a modern economic system. The digital economy has developed into today's most dynamic and innovative economy, generating significant changes in the mode of production, lifestyles and government as the new technological and industrial revolution intensifies. China's 2021 Digital Economy is now the world's second-largest, at $7.1 trillion, according to the China Institute of Information and communications technology. To vigorously develop digital economy and promote the deep integration of digital economy and real economy is an urgent need to create new competitive advantages in the future. Furthermore, it plays a key role in enhancing the export competitiveness of the manufacturing industry and supporting a new development pattern.

Since the reform and opening-up, China's manufacturing industry has participated in the international division of labor through labor endowment, and the relatively extensive economic development mode makes the international trade export and the industrial output value realize the leapfrog development. China's total manufacturing in 2021 reached 31.4 trillion yuan, ranking first in the world for 12 consecutive years. However, with the challenges of rising manufacturing labor costs and key core technologies being "Stuck", the issue of China's manufacturing industry is becoming more and more prominent. In addition, it is affected by unilateralism, trade protectionism and the global COVID-19 epidemic. China's manufacturing exports have also faced many challenges, and enjoying the dividend of digital transformation has become the primary goal of future strategic planning of traditional manufacturing industry.

In this context, how well does the digital economy integrate with manufacturing export competitiveness? Can the development of China's digital economy enhance the competitiveness of its manufacturing exports? Are there differences in the impact on different technology content of manufacturing and different regions? Based on panel data of 30 provinces (cities) in China, this paper measures the degree of integration of the digital economy and the technological complexity of manufacturing exports, and empirically tests the influence of the digital economy on the competitiveness of manufacturing exports, which is of great practical significance for further improving the competitiveness of China's manufacturing exports under the development of the digital economy.

The rest of this paper is organized as follows: Section 2 presents a brief review of extant literature, Section 3 describes the research design, Section 4 presents the empirical analysis and Section 5 concludes the paper.

2. Literature review

As a new economic growth point, the digital economy can become a fulcrum and an important engine to enhance the competitiveness of manufacturing exports. Scholars around the world have also carried out theoretical and empirical research on the digital economy and manufacturing industry. The research on the issues related to the digital economy is mainly about the definition of digital economy, the measurement of digital economy and the impact of digital economy on economic development. Stigler pointed out that information is a valuable resource [1], and the information economy regards information as a key element to explore its value and contribution in economic activities. With the increasingly prominent role of the Internet in economic activities, the term Internet economy was first coined by American economist John Flower. In the Internet economy, the economic activities of economic agents are increasingly dependent on information networks, and information is changing the economic behavior of enterprises and consumers. The concept of Digital Economy was first proposed by Don Tapscott, after which scholars defined the concept of digital economy. Kim et al. pointed out that the digital economy is a special economy in which all goods and services are traded in digital form [2]. The Hangzhou G20 (2016) Summit pointed out that the digital economy is a range of economic activities. Specifically, it refers to economic activities that use digitized knowledge and information as key factors of production, modern information networks as important carriers, and the effective use of information and communication technology as an important driving force for efficiency enhancement and economic structure optimization.

The study of digital economy measurement can be divided into two aspects: satellite account design of digital economy, and development evaluation index construction. By defining the scope of digital economy and constructing satellite accounts of digital economy [3], the contribution of digital economy to GDP can be measured [4,5], and the national economic accounting system can be improved [6]. The Organization for Economic Cooperation and Development (OECD) constructed a digital economy index system covering 4 first-level indicators and 38 second-level indicators with international comparability [7]. In 2014, the European Union released the Digital Economy and Society Index (DESI), which is calculated according to 31 secondary indicators in five aspects, including broadband access, human capital, internet application, digital technology application, and digital public service level, and depicted the development degree of the digital economy in each country of the European Union [8]. It reflected the development level of the EU's digital economy. The China Academy of Information and Communications Technology (CAICT) also released the Digital Economy Index in 2017, which measures China's economic climate over different periods through three categories of leading indicators, consistent indicators, and lagging indicators. Digital technology plays a unique advantage in the fields of education [9], industry [10] and healthcare [11], and promotes the deep integration of the digital economy and the real economy through industrial digitization and digital industrialization.

In previous studies, researchers often divided the main factors affecting competitiveness into labor cost [12], technological progress [13], and foreign direct investment (FDI) [14]. Chen, Peng, and Tsai studied how the market structure of the intermediate sector is determined and how it affected the production decisions, export methods, and market structure of the manufacturing industry [15]. Hayakawa et al. [16] empirically tested the impact of foreign direct investment (FDI) liberalization in the service sector on the quality upgrading of Chinese firms' export enterprises. Wu, Hitt, and Lou [17] analyzed the impact of the digital economy on enterprises from the corporate level, pointing out that companies can gain the greatest benefits from data analysis and enhance their competitiveness. In addition, researchers studied the factors influencing the competitiveness of manufacturing exports in terms of environmental regulations and exchange rates [18,19].

Researchers paid more attention to the impact of digital technology development on the manufacturing industry. Li, Wen, and Liu [20] used panel data from Chinese firms to explore the impact of digital transformation on innovation efficiency. Caputo, Marzi, and Pellegrini [21] explained the impact of the Internet of Things on the evolution of the manufacturing industry, and pointed out that the emergence of the Internet of Things can enable relevant enterprises to effectively control technological changes and competition. Giudice believed that the Internet of Things has an important impact on promoting knowledge flow, innovation, competitiveness, and Internet of Things technology had become an important driving force for the transformation and upgrading of the manufacturing industry [22]. Wang and Li's empirical results showed that cross-country differences in ICT can be a source of comparative advantage in international trade [23]. Banga [24] found that investing in digital capability has a positive and significant impact on firm-level product sophistication. Atasoy [25] pointed out that exports get more sophisticated as digitalization promotes them. Gopalan, Reddy, and Sasidharan [26] empirically tested the importance of digitalization in deepening GVC participation, and the empirical analysis showed that digitalization by firms positively influences GVC deepening.

From the existing literature, on the one hand, there is no scientific and unified indicator system to measure the development level of the digital economy. Therefore, it is necessary to measure the development level of the digital economy through suitable indicators. Four areas are examined in our study of the digital economy: infrastructure, innovation capability, core industry development and integrated applications. In this paper, we use principal component analysis to evaluate the contribution of individual indicators of the digital economy to reflect the development of China's digital economy as comprehensively as possible. On the other hand, academic literature rarely focuses on the link between manufacturing export competitiveness and digital economy from the perspective of empirical economics, which may be an important innovation driver of manufacturing export competitiveness. From the perspective of the digital economy, we empirically test the impact of digital economy on China's manufacturing export competitiveness, and illustrate the influence of digital economy on China's manufacturing export competitiveness, which provides experience for China and other developing economies to enhance manufacturing export competitiveness.

3. Research design

3.1. Variable description

3.1.1. Measurement of technical complexity of manufacturing exports

The independent variable of this paper, namely export competitiveness of manufacturing industry, is expressed by the complexity of export technology of manufacturing industry. We calculate the export technical complexity of China's manufacturing export based on the formula proposed by Hausmann, Hwang, and Rodrik [27]:

$$PRODY_p = \sum_j \frac{x_{jp}/X_j}{\sum_j (x_{jp}/X_j)} Y_j \tag{1}$$

$PRODY_p$ stands for the result of the export technical complexity of manufacturing p. It shows the export sophistication of each manufacturing industry. x_{jp} is the export volume of p of j, X_j is the gross export volume of j and Y_j is the per capita GDP of province j. $PRODY_p$ measures the technical complexity of manufacturing export at the national level. Then, the following formula is used to calculate the provincial level:

$$EXPY_i = \sum_j \frac{x_{jp}}{X_j} PRODY_p \tag{2}$$

where $EXPY_p$ stands for technical complexity of manufacturing export in province i. x_{jp} is the export volume of p of j and X_j is the gross export volume of j. $PRODY_p$ represents the export technical complexity of manufacturing.

We matched the China's National Economic Classification of Industries with the General HS Commodity classification for international trade, and finally got 16 samples of manufacturing data. The data used in Eqs (1) and (2) are from these manufacturing industries. Table 1 classifies these 16 manufacturing industries into low-technology manufacturing, medium-technology manufacturing and high-technology manufacturing, according to the technology content of each manufacturing industry.

Table 1. Manufacturing classifications.

Manufacturing sector classified by technical content	Manufacturing categories and their matching HS codes
Low-tech manufacturing	HS16–24 (Agricultural and Sideline Food Processing Industry, Food Producing Industry, Wine, Beverage and Fine Tea Manufacturing, Tobacco manufacturing), HS41–43, 50–67 (Textile Industry, Textile and Garment industry, Leather, Furs, Feathers and Their Products and Footwear), HS44–46 (Wood Processing and Wood, Bamboo, Rattan, Palm, and Grass Products), HS94 (Furniture Manufacturing), HS47–49, 95 (Paper and Paper Products Industry, Printing and Recording Media Reproduction Industries, Education, Arts and Crafts, Sports and Entertainment Manufacturing), HS96 (Other Manufacturing Industry)
Medium-tech manufacturing	HS27 (Oil, Coal and Other Fuel Processing Industries), HS28–29, 31–36, 38 (Manufacturing of Chemical Raw Materials and Chemical Manufactured Products, Chemical Fiber Manufacturing), HS39, 40 (Rubber and Plastic Products), HS25, 26, 68–70 (Manufacture of Non-metallic Mineral Products), HS71–83 (Ferrous Metal Smelting and Calendering Industry, Non-ferrous Metal Smelting and Calendering Industry, Metal Products Industry)
High-tech manufacturing	HS30 (Pharmaceutical Manufacturing), HS84, 85 (General Equipment Manufacturing, Special Equipment Manufacturing), HS87 (Automobile Industry), HS86, 88, 89 (Railway, Marine, Aerospace and Other Transportation Equipment Manufacturing), HS90, 91 (Railway, Marine, Aerospace and Other Transportation Equipment Manufacturing)

Among the 16 types of manufacturing industries in Table 1, low-technology manufacturing industries are labor-intensive manufacturing industries, and medium- and high-technology manufacturing industries are capital-intensive manufacturing industries. Equations (1) and (2) are used to further calculate the data on the technological complexity of manufacturing exports in each province (city) of China, and the results are shown in Table 2. From 2013 to 2019, the technological complexity of manufacturing export in all regions increased year by year. Beijing, Shanghai, Jiangsu, Tianjin and other provinces (cities), by virtue of the export of mechanical and electrical equipment, electrical equipment, transportation vehicles, electronic products, electrical products, instruments and other mechanical and electrical products, show that their exports of technical complexity are far ahead of other provinces (cities). The exports of clothes, shoes and other products made in Fujian and Guangdong provinces are also concentrated and specialized.

According to the results in Table 2, Figure 1 shows the specific differences in the technical complexity of manufacturing exports in 30 provinces (cities). From 2013 to 2019, the technical complexity of manufacturing exports in each province showed an increasing trend. The overall technical complexity of manufacturing exports in the eastern provinces (cities) is higher than that in the central and western provinces (cities).

Table 2. Manufacturing export technology complexity in various regions from 2013 to 2019.

Area	Manufacturing export technology complexity						
	2013	2014	2015	2016	2017	2018	2019
Beijing	1.6239	1.7375	1.8254	1.8577	2.0168	2.2813	2.3451
Tianjin	1.1520	1.2203	1.2181	1.1991	1.2927	1.4460	1.4722
Hebei	0.5384	0.5617	0.5779	0.5824	0.6139	0.6620	0.6818
Shanxi	0.5465	0.5575	0.5394	0.5114	0.6108	0.6878	0.7026
Neimenggu	0.7479	0.8072	0.8505	0.8515	0.9064	1.0048	1.0317
Liaoning	0.7097	0.7475	0.7463	0.7086	0.7438	0.8260	0.8410
Jilin	0.5674	0.6111	0.6122	0.6061	0.6352	0.6789	0.6893
Heilongjiang	0.5178	0.5448	0.5260	0.5122	0.5315	0.5773	0.5966
Shanghai	1.5460	1.6739	1.7530	1.8272	1.9771	2.2028	2.2222
Jiangsu	1.1750	1.2814	1.3787	1.3950	1.5137	1.6700	1.6909
Zhejiang	1.0512	1.1162	1.1765	1.1801	1.2680	1.4089	1.4318
Anhui	0.5555	0.6118	0.6373	0.6577	0.7271	0.8472	0.8779
Fujian	0.9406	1.0371	1.0861	1.1144	1.2405	1.4314	1.4890
Jiangxi	0.5159	0.5696	0.6011	0.6165	0.6647	0.7608	0.7921
Shandong	0.7859	0.8454	0.9024	0.8918	0.9330	1.0017	1.0133
Henan	0.5347	0.5858	0.6155	0.6222	0.6772	0.7664	0.7879
Hubei	0.7078	0.7917	0.8352	0.8558	0.9356	1.0744	1.1120
Hunan	0.5765	0.6378	0.6929	0.7017	0.7558	0.8276	0.8713
Guangdong	0.9047	0.9753	1.0358	1.0489	1.1289	1.2335	1.2605
Guangxi	0.4265	0.4656	0.4960	0.5019	0.5397	0.6020	0.6201
Hainan	0.5498	0.6050	0.6375	0.6475	0.6906	0.7596	0.7817
Chongqing	0.7028	0.7865	0.8426	0.8781	0.9504	1.0345	1.0776
Sichuan	0.5288	0.5789	0.5965	0.6067	0.6789	0.7806	0.8062
Guizhou	0.3567	0.4086	0.4583	0.4756	0.5330	0.6086	0.6339
Yunnan	0.4467	0.4919	0.5157	0.5277	0.5844	0.6717	0.7150
Shaanxi	0.6766	0.7425	0.7491	0.7428	0.8178	0.9236	0.9496
Gansu	0.3818	0.4188	0.4166	0.4124	0.4310	0.4863	0.5031
Qinghai	0.4845	0.5245	0.5601	0.5867	0.6252	0.7080	0.7244
Ningxia	0.5673	0.5993	0.6081	0.6073	0.6771	0.7498	0.7616
Xinjiang	0.5972	0.6543	0.6345	0.6025	0.6735	0.7743	0.7761

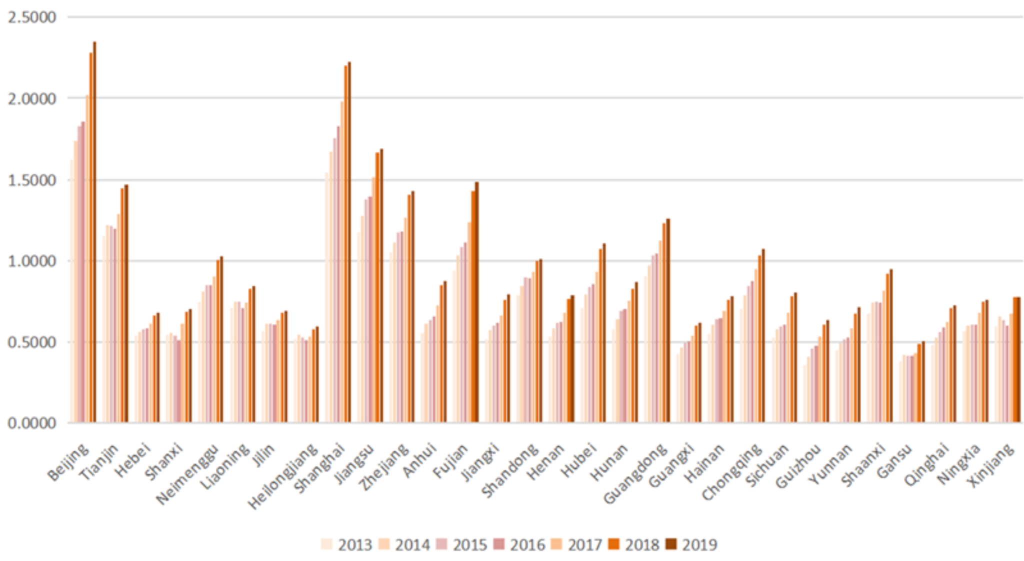

Figure 1. Manufacturing export technology complexity in each province (City).

3.1.2. Measurement of the development level of the digital economy

Our main explanatory variable—the development level of the digital economy (DE)—takes into account the availability of statistical data, long-term observability and continuity. We identified four primary indicators: infrastructure, innovation capability, development of core industry and integrated application to measure it.

Among the primary indicators, infrastructure includes four secondary indicators: length of optical cable lines, base stations of mobile phones, number of domain names and broadband subscribers port of internet; innovation capability includes full–time equivalent of R&D personnel, expenditure on R&D and number of inventions in force; development of core industry include a number of enterprises, fixed asset investment, total profits and number of employees in software and information technology service industry. The integrated application of the digital economy includes software income and sales of e-commerce.

On the basis of the constructed digital economy development evaluation index system, the weights of each index were calculated by using the principal component analysis method [28,29].

First, in order to eliminate the influence of different levels of indicators on the data analysis results, the original data were standardized according to the following formula.

$$X_{ij}^{'} = \frac{X_{ij} - min(X_j)}{max(X_j) - min(X_j)} \tag{3}$$

X_{ij} is the original data, $max(X_j)$ and $min(X_j)$ are the maximum and minimum value of indicators, respectively.

Second, Bartlett's test of sphericity and Kaiser-Meyer-Olkin (KMO) test were performed on this group of data using SPSS 22.0. The results in Table 3 show that the KMO test statistic of the data was 0.897, and the Bartlett sphericity test result was less than 0.01, indicating that this group of data was suitable for factor analysis.

Table 3. Results of the Kaiser-Meyer-Olkin measure of sampling adequacy and Bartlett's test of sphericity.

Test		Results
Kaiser-Meyer-Olkin measure of sampling adequacy		0.897
Bartlett's test	Approx. Chi-square	4646.111
	df	78
	Sig.	0.000

Table 4. Total variance explained.

Items	Initial eigenvalue			Extraction Sums of Squared Loadings		
	Total	Percentage of variance	Cumulative addition of items %	Total	Percentage of variance	Cumulative addition of items %
1	9.448	72.677	72.677	9.448	72.677	72.677
2	1.313	10.104	82.781	1.313	10.104	82.781
3	0.762	5.865	88.646			
4	0.506	3.896	92.541			
5	0.300	2.306	94.847			
6	0.256	1.971	96.818			
7	0.144	1.109	97.927			
8	0.108	0.831	98.758			
9	0.056	0.428	99.186			
10	0.035	0.269	99.455			
11	0.034	0.259	99.714			
12	0.022	0.168	99.881			
13	0.015	0.119	100.000			

Table 5. Component Matrix.

Items	Factor 1	Factor 2
1	0.734	0.629
2	0.832	0.482
3	0.677	-0.254
4	0.871	0.438
5	0.915	0.113
6	0.942	0.099
7	0.884	0.015
8	0.857	-0.292
9	0.751	-0.119
10	0.926	-0.127
11	0.907	-0.319
12	0.923	-0.321
13	0.814	-0.294

Third, factor analysis of data was continued with SPSS 22.0, and variance contribution Table 4 and component matrix Table 5 could be obtained.

Factors are extracted based on the principle that the eigenvalue is greater than 1. The cumulative variance contribution of the first two factors is 82.781%, which ensures that the composite variables can contain most of the information of the original variables. Therefore, the first two factors are selected to replace the original 13 indicators.

Finally, the score coefficients of each factor were calculated using the data of the component matrix and total variance interpretation, and the weights of each index were obtained by normalization, as shown in Table 6.

Table 6. Digital economy development evaluation index system and weight.

Primary indicators	Secondary indicators
Infrastructure (0.3254)	Length of optical cable lines (0.0876)
	Base stations of mobile phone (0.0916)
	Number of domain names (0.0527)
	Broadband subscribers port of internet (0.0936)
Innovation capability (0.2558)	Full–time equivalent of R&D personnel (0.0866)
	Expenditure on R&D (0.0886)
	Number of inventions in force (0.0805)
Development of core industry (0.2824)	Number of enterprises in software and information technology service industry (0.0676)
	Fixed asset investment in software and information technology service industry (0.0639)
	Total profits in software and information technology service industry (0.0795)
	Number of employees in software and information technology service industry (0.0713)
Integrated application of digital economy (0.1364)	Software income (0.0727)
	Sales of e-commerce (0.0637)

Based on the weights and data of each indicator, the development level of digital economy in each province (city) of China from 2013 to 2019 was calculated, and the results are shown in Table 7 and Figure 2. From 2013 to 2019, the inter-provincial digital economy of China showed positive growth. It can be seen that the digital economy has become a new engine of economic growth for each province, and has a significant role in promoting China's economic growth. Specifically, Guangdong, Jiangsu, Zhejiang, Shandong and Beijing provinces (cities) rely on digital infrastructure and digital industry advantages, with the level of development of the digital economy in the forefront of the country. In addition, Qinghai, Ningxia and Hainan have a low level of digital economy development, and have great development potential. However, it is undeniable that the inter-provincial gap in China's digital economy development is more pronounced, and the follow-up should continue to promote precise regional digital economy development. We should continue to promote precise regional digital economy development initiatives to gradually reduce regional differences.

Table 7. The development level of digital economy in various regions from 2013 to 2019.

Area	The development level of digital economy						
	2013	2014	2015	2016	2017	2018	2019
Beijing	0.1861	0.2122	0.2482	0.2801	0.3146	0.3464	0.3931
Tianjin	0.0497	0.0592	0.0687	0.0740	0.0675	0.0755	0.0820
Hebei	0.0781	0.0905	0.1140	0.1424	0.1634	0.1767	0.1986
Shanxi	0.0419	0.0507	0.0585	0.0681	0.0793	0.0935	0.1020
Neimenggu	0.0269	0.0319	0.0417	0.0517	0.0618	0.0613	0.0788
Liaoning	0.1689	0.1887	0.1852	0.1637	0.1761	0.1744	0.1990
Jilin	0.0384	0.0451	0.0528	0.0613	0.0658	0.0758	0.0801
Heilongjiang	0.0453	0.0526	0.0581	0.0663	0.0799	0.0721	0.0863
Shanghai	0.1423	0.1890	0.2100	0.2116	0.2208	0.2348	0.2605
Jiangsu	0.3838	0.4583	0.5535	0.5891	0.6434	0.7103	0.7500
Zhejiang	0.2226	0.2686	0.3341	0.3789	0.4387	0.4679	0.5374
Anhui	0.0696	0.0874	0.1137	0.1376	0.1617	0.1887	0.2131
Fujian	0.1131	0.1425	0.1780	0.2203	0.2687	0.2828	0.2884
Jiangxi	0.0398	0.0486	0.0660	0.0803	0.1074	0.1219	0.1435
Shandong	0.2469	0.2896	0.3380	0.3867	0.4280	0.4656	0.4841
Henan	0.1299	0.1161	0.1487	0.1830	0.1917	0.2061	0.2278
Hubei	0.1134	0.1374	0.1669	0.1916	0.2085	0.2403	0.2729
Hunan	0.0800	0.0985	0.1169	0.1346	0.1608	0.1785	0.2091
Guangdong	0.4214	0.4809	0.5581	0.6350	0.7176	0.8203	0.8940
Guangxi	0.0401	0.0482	0.0602	0.0752	0.0849	0.0982	0.1319
Hainan	0.0051	0.0083	0.0144	0.0181	0.0221	0.0275	0.0366
Chongqing	0.0527	0.0701	0.0871	0.1259	0.1277	0.1442	0.1665
Sichuan	0.1233	0.1559	0.1943	0.1737	0.2590	0.2942	0.3365
Guizhou	0.0297	0.0338	0.0478	0.0593	0.0721	0.0825	0.1038
Yunnan	0.0362	0.0448	0.0618	0.0965	0.0820	0.1029	0.1285
Shaanxi	0.0665	0.0809	0.0990	0.1100	0.1213	0.1528	0.1894
Gansu	0.0211	0.0243	0.0328	0.0418	0.0499	0.0560	0.0632
Qinghai	0.0014	0.0032	0.0066	0.0085	0.0090	0.0116	0.0147
Ningxia	0.0025	0.0042	0.0062	0.0095	0.0129	0.0157	0.0187
Xinjiang	0.0239	0.0306	0.0409	0.0532	0.0586	0.0781	0.0774

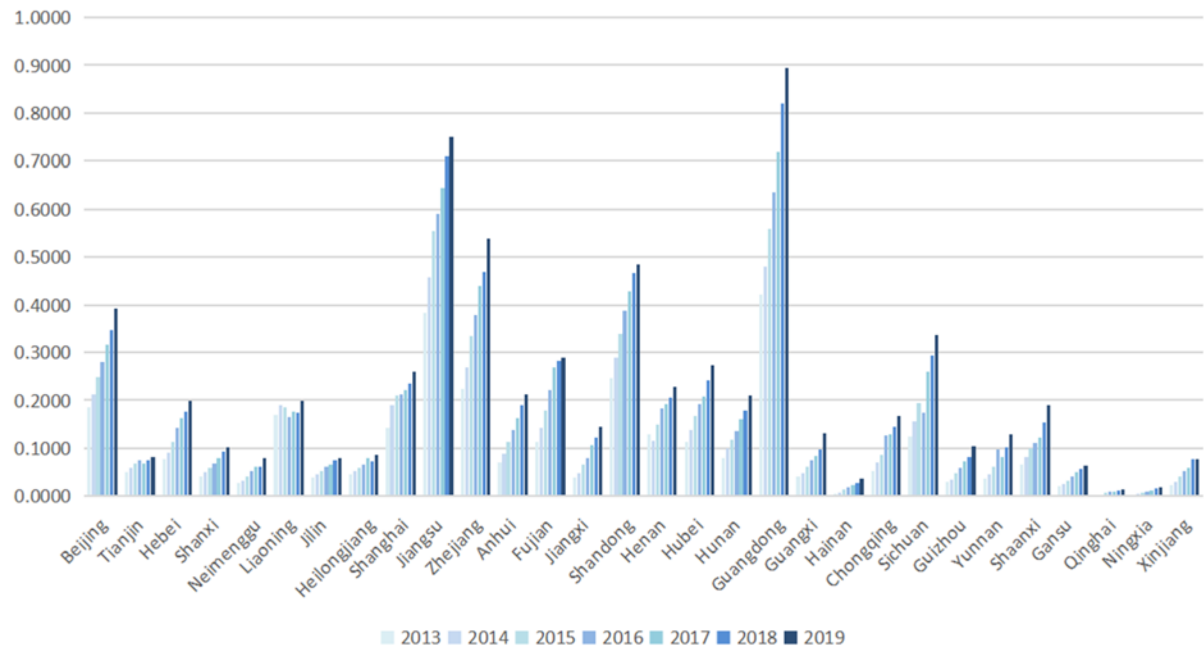

Figure 2. The development level of digital economy in each province (City).

3.1.3. Control variables

As for the control variables, following the literature, we control for five groups of indicators: product structure (PRO), industrial structure (IND), technological innovation (TEC), opening level (OPEN) and human capital level (EDU). Among them, the structure of trade products to high-tech products (select the Chinese customs code for 16–18 categories of goods) exports accounted for the proportion of total trade. The industrial structure level is expressed by the ratio of the tertiary sector of the economic value-added to the secondary sector of the economy value-added in different regions. The level of technological innovation is expressed by the number of invention patent applications per thousand people in each region. The level of openness is measured by the proportion of total imports and exports to GDP in each region. The level of human capital in each region is expressed as the ratio of the number of people with a university degree or higher to the total number of employed people in each region.

3.2. Data and description

There are three main data sources in this paper, which are the China Statistical Yearbook of the National Bureau of Statistics of China (http://www.stats.gov.cn/tjsj/ndsj/), the China Industrial Statistics Database (https://data.drcnet.com.cn/dataTable?id=43&structureId=946) of the National Research Network and the Foreign Trade Database (https://data.drcnet.com.cn/dataTable?id=16&structureId=937) of the National Research Network. In this paper, data related to 30 Chinese provinces (cities) for the years 2013–2019 are collected. In addition, descriptive statistics of each variable are given in Table 8.

Table 8. Descriptive statistics of data.

Variable	Obs	Mean	Std. Dev.	Min	Max
EXPY	210	0.8532	0.3946	0.3567	2.3451
DE	210	0.1615	0.1640	0.0014	0.8940
PRO	210	0.4112	0.2229	0.0276	0.8798
IND	210	1.2539	0.6829	0.5722	5.1692
TEC	210	0.7620	0.9361	0.0786	5.9329
EDU	210	0.1988	0.0995	0.0833	0.6220
OPEN	210	0.2630	0.2687	0.0128	1.2571

3.3. Methodology

To explore the degree of integration between China's digital economy and manufacturing export competitiveness, a coupling coordination model is used to evaluate the level of coupling coordination between China's digital economy development and manufacturing export competitiveness. The formulas are as follows:

$$D = \sqrt{C \times T} \tag{4}$$

$$C = \frac{2\sqrt{U \times V}}{(U + V)} \tag{5}$$

$$T = \alpha U + \beta V \tag{6}$$

In Eq (4), D denotes the coupling degree between the digital economy development U and the manufacturing export competitiveness V, C denotes the coupling degree between the two, and T denotes the comprehensive development index of the two subsystems. In Eq (6), the undetermined coefficients α and β are set at 0.5. The coupling coordination degree D ranges from 0 to 1. The coupling coordination degree is divided into five grades, which are as follows: (0, 0.2), severely coupling coordination, (0.2, 0.4), moderate coupling stage, (0.5, 0.8), high coupling stage, (0.8, 1), extreme coupling stage.

The question we seek to examine is whether the export competitiveness of China's manufacturing industry is influenced by the development level of the digital economy. Based on this, the model is designed as follows.

$$EXPY_{it} = \alpha_0 + \alpha_1 DE_{it} + \alpha_2 CO_{it} + \mu_i + \sigma_t + \varepsilon_{it} \tag{7}$$

where, i is each subdivided manufacturing industry and t is time. $EXPY_{it}$ is the explained variable, which is expressed using the export technology complexity calculated in Eq (2). DE_{it} is the core explanatory variable-the development level of digital economy. CO_{it} is the control variable, μ_i is the individual fixed effect, σ_t is the time fixed effect and ε_{it} is the random disturbance term.

4. Empirical analysis

4.1. Analysis of coupling coordination degree

From the time dimension, the coupling and coordination between the digital economy and the manufacturing export competitiveness of 30 Chinese provinces (cities) from 2013 to 2019 are significantly enhanced, with all moving towards a higher level of coordination. Specifically, the coordination between China's digital economy and manufacturing export competitiveness is weakening from east to west. The eastern region is always ahead of the central and western regions in coordination. From the perspective of inter-provincial, Guangdong, Beijing, Jiangsu, Zhejiang and other provinces and cities than other provinces (cities) relate to a higher degree of coupling and coordination. It may be that these provinces (cities) have obvious regional advantages, which are conducive to promoting the deep integration and effective interaction between digital economy and manufacturing industry.

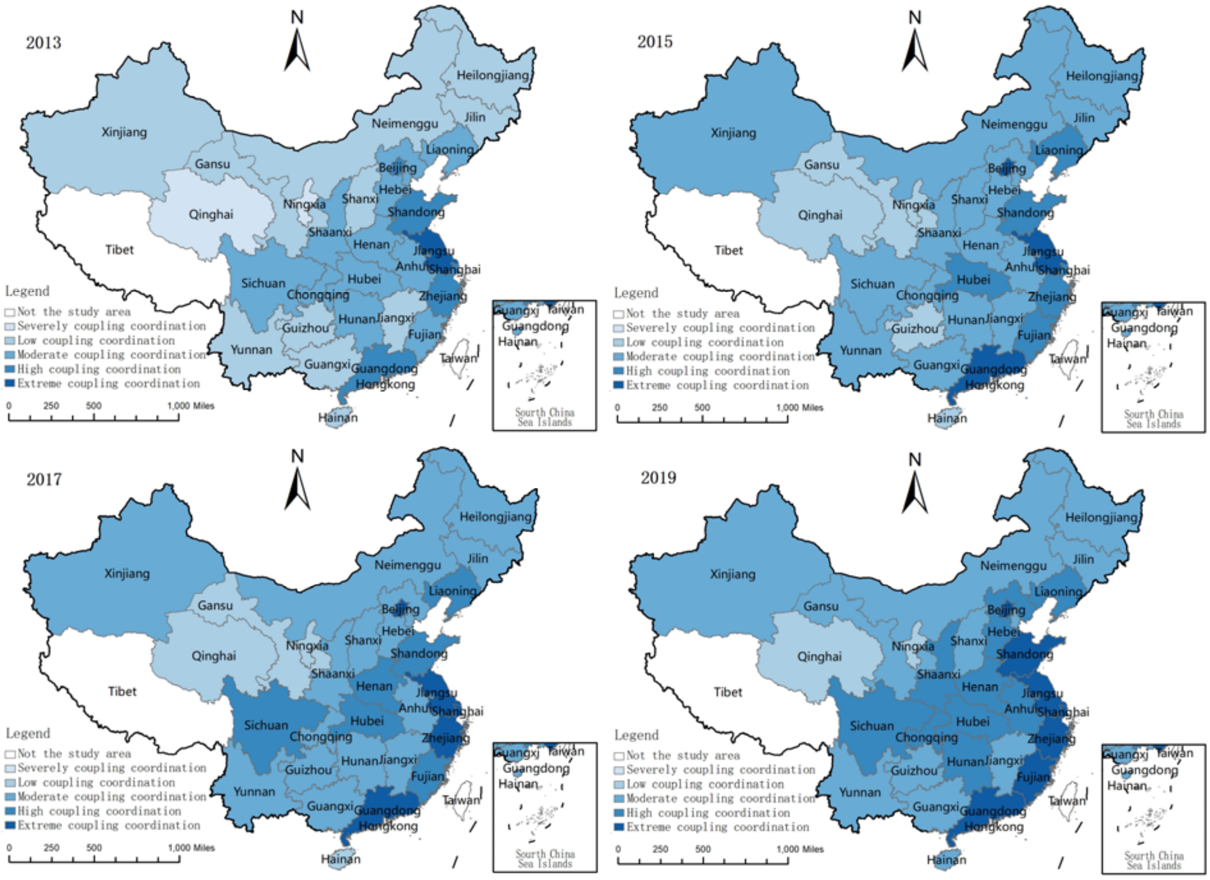

Figure 3. Time-space evolution of coupling coordination degree between digital economy and manufacturing export competitiveness. (Note: This map is based on the national standard map of the Ministry of Natural Resources (examination number: GS (2020)4632). The base map has not been modified.)

From the above analysis, it can be seen that the eastern region has a high degree of integration of digital economy and manufacturing export technology, while the central and western regions have a large potential for integration. Therefore, the next part is to explore whether China's digital economy development can enhance its manufacturing export competitiveness, and provide relevant empirical reference for further enhancing the competitiveness of China's manufacturing exports.

4.2. Analysis of benchmark regression results

Table 9 reports the results of the benchmark regressions of the impact of the digital economy on manufacturing export competitiveness estimated using the two-way fixed effects estimation method. First, the OLS regression is used to determine whether the development of China's digital economy has a positive impact on manufacturing export competitiveness without considering the influence of control variables. The regression results are shown in column (1) of Table 9. Housman test results show that this problem can be estimated using fixed-effects models. Therefore, this paper uses a two-way fixed-effects model for the next estimation of the problem without adding control variables. The results are presented in column (2) of Table 9. Finally, the model was re-estimated with the addition of control variables, and the results are presented in column (3) of Table 9.

Table 9. Benchmark regression results.

Variable	OLS EXPY	FE EXPY	FE EXPY
DE	1.3992***	0.6725***	0.1952**
	(0.1368)	(0.1015)	(0.0958)
PRO			-0.2385***
			(0.0564)
IND			-0.0754***
			(0.0272)
TEC			0.1112***
			(0.0166)
EDU			0.3775*
			(0.2239)
OPEN			-0.1515*
			(0.0745)
Constant	0.6304***	1.6671***	1.6671***
	(0.0314)	(0.0317)	（0.2009）
Provincial effect	NO	YES	YES
Time effect	NO	YES	YES
Observations	210	210	210

Note: Standard errors in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. The table below is the same.

The results in Table 9 confirm that the digital economy does have a positive and significant impact on manufacturing export competitiveness. This conclusion provides the basis for China to cultivate new drivers for manufacturing development, accelerate the development of the digital economy and use the digital economy to drive the enhancement of global competitiveness in manufacturing. Driven by the widespread use of application of information technology such as big data, cloud computing and the Internet of things [29], China's digital economy has flourished, and in the digital economy scale, the growth rate, the infrastructure and the application scene and so on, show that many aspects are in the global leading ranks for China's manufacturing industry to cope with the international market environment change, improving the export competitiveness of manufacturing provides an important opportunity.

From the regression results of the control variables, the effects of technological innovation and human capital level on manufacturing export competitiveness are significantly positive. This indicates that accelerating digital innovation and improving the level of technological innovation can stimulate China's innovation dynamics. Through the development and application of information technology, we can continuously improve the efficiency of innovation and effectively promote the growth of R&D investment, and promote the transformation of China's manufacturing exports from quantitative accumulation to qualitative improvement. In addition, in the era of digital economy, the improvement of human capital quality in each region of China can better realize the high-quality development of manufacturing industry, and give full play to the role of human capital investment in promoting the competitiveness of manufacturing exports.

4.3. Analysis of heterogeneity test results

The results of the baseline regression show that the development of China's digital economy has a significant positive impact on the improvement of manufacturing export competitiveness. There may be heterogeneity in different technology-intensive manufacturing industries and different geographical locations of provinces. Therefore, according to the technical content, the manufacturing industry is divided into low-tech manufacturing industry, medium-tech manufacturing industry and high-tech manufacturing industry. The samples are divided into eastern, central and western regions according to the regions of the provinces. Then, the heterogeneous impact of the development of the digital economy on manufacturing export competitiveness is further discussed, and the specific regression results are shown in Table 10.

Table 10. Heterogeneity test results.

	Based on technical intensity			Based on regions of the provinces		
	Low-tech	Medium-tech	High-tech	West	Central	East
DE	0.1128	-0.2422*	0.3246***	0.6010***	2.1443***	-0.1151
	(0.0742)	(0.1288)	(0.0917)	(0.1462)	(0.1748)	(0.1711)
PRO	-0.2465***	-0.8044***	0.8124***	-0.0293	0.0461	-0.6293***
	(0.0437)	(0.0758)	(0.0564)	(0.0523)	(0.0450)	(0.1431)
IND	-0.1022***	0.0911**	-0.0642**	-0.0878***	-0.0679***	-0.1605**
	(0.0210)	(0.0365)	(0.0260)	(0.0324)	(0.0191)	(0.0673)
TEC	-0.0152	0.1391***	-0.0127	0.0237	-0.0141	0.1136***
	(0.0128)	(0.0223)	(0.0166)	(0.0254)	(0.0175)	(0.0316)
EDU	-0.2540	-0.0636	0.6951***	0.1153	-0.4696*	1.2900***
	(0.1734)	(0.3009)	(0.2239)	(0.2274)	(0.2598)	(0.4229)
OPEN	-0.0923	0.1396	-0.1988***	-0.1248	-0.2655	0.1870
	(0.0577)	(0.1001)	(0.0713)	(0.1258)	(0.1512)	(0.1236)
Constant	0.9302***	0.0820**	0.6550***	0.8171***	0.5702	1.8410***
	(0.1556)	(0.2700)	（0.1923）	(0.0559)	(0.0500)	(0.3704)
Provincial effect	YES	YES	YES	YES	YES	YES
Time effect	YES	YES	YES	YES	YES	YES
Observations	210	210	210	77	56	77

The results show that the development of digital economy has significantly improved the export competitiveness of high-tech manufacturing, but has little impact on low- and medium-tech manufacturing. In general, the labor quality of the high-tech manufacturing industry is relatively high, which may trigger the complementary effect of the digital economy and high-skilled labor. Further, with the support of digital technology, high-tech manufacturing can optimize the production process and organization form, improve production efficiency and economic benefits, and enhance its export scale competitiveness. The digital economy has no significant influence on the export scale competitiveness of low- and medium-technology manufacturing industries. The reasons for this may lie in: at present, as a new economic form, the overall development of the digital economy is still in its infancy, and the low and medium technology manufacturing industry is mostly labor-intensive industry, where the degree of industrial digitalization and the degree of integration with digital economy is low, and the two have not formed a benign integration and interaction.

From a regional perspective, the digital economy can significantly improve the competitiveness of manufacturing exports in the central and western regions, while the impact on the eastern region is not significant. The reason may be that, on the one hand, the eastern region has been ahead of the central and western regions in the level of digital economy in recent years, and has a high degree of integration with the manufacturing industry itself, meaning the effect on manufacturing export competitiveness is not statistically significant in the observation period. On the other hand, the western and central regions pay more and more attention to the development of digital economy, and use it to enhance the competitive advantage of manufacturing industry, and improve the competitiveness of manufacturing exports.

4.4. Robustness test

Table 11. Robustness test results.

Variable	L.EXPY	EXPY
DE	0.9036***	0.7409***
	(0.3917)	(0.2321)
PRO	-0.2196***	-0.2273***
	(0.0617)	(0.0556)
IND	-0.0221	-0.0658**
	(0.0402)	(0.0265)
TEC	0.0796***	0.1016***
	(0.0278)	(0.0167)
EDU	0.0570	0.3212
	(0.2792)	(0.2209)
OPEN	-0.2113	-0.1144
	(0.1301)	(0.0748)
Constant	1.6718***	1.6224***
	(0.3046)	(0.1965)
Provincial effect	YES	YES
Time effect	YES	YES
Observations	210	210

We consider that the improvement in manufacturing export competitiveness may be sustained to some extent, that is, the export competitiveness of the manufacturing industry in the current period may be affected by the previous period. To this end, we carry out a phase-delay on manufacturing export competitiveness and a re-empirical test of the results. In addition, we used the entropy method to replace the principal component analysis method, re-measure the development level of the digital economy and re-regress the model with the data as the core explanatory variable. The results of the robustness test are shown in Table 11, which are consistent with Table 9, which, again, indicates that the development of China's digital economy has greatly contributed to the increased competitiveness of manufacturing exports, and verifies the robustness of the basic conclusion of this paper.

5. Conclusions

The purpose of this paper is to explore the relationship between the digital economy and China's manufacturing export competitiveness. We construct the digital economy development evaluation index system, and calculate the index weight with the principal component analysis method. Using panel data for the sector from 2013 to 2019, this paper empirically tests the impact of digital economy on the export competitiveness of China's manufacturing industries.

The results show that the digital economy is an important driving factor of China's manufacturing export competitiveness, and its development promotes the improvement of China's manufacturing export competitiveness. Specifically, the development of digital economy has a significant positive impact on the improvement of export competitiveness of high-tech manufacturing industry, but has no significant impact on the export competitiveness of the low-tech and medium-tech manufacturing industries. In terms of different regions, the digital economy has significantly enhanced the manufacturing export competitiveness of the central and western regions, but has no significant impact on the eastern region.

To further promote the development of China's digital economy and enhance the competitiveness of manufacturing exports: First, the government should promote international cooperation on digital economy infrastructure, actively integrate into the global industrial chain of the digital economy, build an international cooperation platform for the digital economy and promote digital economy infrastructure construction and connectivity. Second, optimize the way of digital economy embedding. According to the characteristics of different manufacturing industries and different regions, the government can make targeted and differentiated policies to reasonably optimize the integration of digital economy and manufacturing industries, and deepen the breadth and depth of digital economy embedding, so as to give full play to the pulling effect of digital economy on manufacturing export competitiveness. For low and medium-tech manufacturing industries, the government can give appropriate support to promote the deep integration of low- and medium-tech manufacturing industries with the digital economy, in order to enhance the added value of their products and export competitiveness, so that the level of industrial digitization and digital industrialization can advance to the high end. Third, there is not yet a unified global system of rules governing the digital economy. Countries can actively carry out international cooperation on digital technology innovation, promote the international process of digital economy standardization, coordinate digital economy standards and make rules with other countries, and share the market dividends and technological dividends of transnational cooperation.

Based on data on China's digital economy development and manufacturing exports from 2013 to 2019, using econometric methods, we explore the specific impact of China's digital economy development on manufacturing export competitiveness. However, there are still some limitations: 1) Due to the late start of China's digital economy development, we collected data from 2013 to 2019, and the sample size is not large enough, so the empirical test results may be biased. 2) The impact of China's digital economy development on manufacturing export competitiveness is mainly studied, and, therefore, the impact of uncertainties, such as trade frictions and policy changes on manufacturing export competitiveness, which may have a significant impact on manufacturing export competitiveness, is not considered. 3) Principal component analysis was used to measure the weights of each indicator of digital economy development, and Stata software was used to empirically test the specific impact of digital economy on China's manufacturing export competitiveness. However, limited data lead to some bias in the econometric test results. In recent years, the scale of China's digital economy has steadily expanded with technological innovation and rising demand. In future research, issues, such as the impact mechanism of digital economy on manufacturing export competitiveness, can be further investigated. In addition, as more and more data become available, further exploration of the impact of the digital economy on the competitiveness of manufacturing exports can be done using methods, such as machine learning.

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Conflict of interest

We declare there are no conflicts of interest.

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