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Research on the Relationship between Digitalization Level of Manufacturing and Trade Network Position—Based on Value-added Trade

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ABSTRACT
As globalization continues to deepen, the digital economy has become a new driving force for economic development in the context of the new economy. This paper constructs a trade network based on WIOD value-added trade data and finds through empirical analysis that the level of digitalization has a significant positive effect on the enhancement of a country's position in the trade network, a conclusion that still holds after robustness tests. Heterogeneity analysis reveals that the role of digitalization in promoting the manufacturing industry of developing countries is stronger than that of developed countries, and the promotion is more evident in technology-intensive and labor-intensive sectors. Based on the above conclusions, this paper attempts to analyze and propose corresponding policy recommendations.

KEYWORDS
Digitalization; Value-added Trade; Trade Network; Social Network Analysis (SNA)

1 Introduction

Against the backdrop of globalization and digitalization, the digital economy has become a key force in driving global economic growth and innovation. The "14th Five-Year Plan for Digital Economy Development" clearly states that the digital economy is a new economic form characterized by data resources as key elements, modern information networks as the main carriers, and the integration and application of information and communication technologies and the digital transformation of all factors as important driving forces. The plan emphasizes the key role of digital transformation in promoting profound changes in modes of production, lifestyles, and governance, and sets goals for comprehensively deepening the digital transformation of key industries, with specific requirements for the digital transformation of manufacturing. The "Overall Layout Plan for Building a Digital China" proposes a holistic framework for constructing a digital China, highlighting the importance of digital infrastructure and data resource systems, and sets goals for advancing the deep integration of digital technology with the economy, which has significant guiding significance for the digital transformation of manufacturing. These policy documents together form a policy framework that supports the digital transformation of manufacturing and enhances its position in the trade network, demonstrating the national emphasis and determination to promote the digital transformation of manufacturing. Through the implementation of these policies, it can be anticipated that digitalization will bring broader development space and stronger international competitiveness to the manufacturing industry. In this context, studying how digitalization levels affect the trade network position of the manufacturing industry from the perspective of international trade networks is of great significance.

2 Literature Review

2.1 Research on Trade Networks

As global trade continues to deepen, the international trade network is being perfected, attracting more and more scholars to examine the impact of a country's position in the trade network from the perspective of trade networks. In the study of the characteristics and trends of global trade networks, scholars have measured the characteristics of trade networks in different years to observe the overall changes in the global trade network. Xu and Lian et al. (2015) constructed a trade network using manufacturing trade values and analyzed the changes in the characteristics of the world's manufacturing trade network. Ma and Jing et al. (2024) found that the global digital trade network has a significant "core-periphery" structure, while Cui and Fu Chen (2024) found that China's position in the manufacturing trade network in the East Asian region is gradually rising. Wu Yilin et al. (2024) used RCA as the weight to construct a trade network and found that China's digital competitiveness of products is among the world's forefront.

In the research on the impact of trade network characteristics on economic development, scholars such as Ma Shuzhong et al. (2016), Chen Lian et al. (2018), Liu Zhen et al. (2023), Blázquez et al. (2023), Shi Jianxun et al. (2024), Ma Dan et al. (2024), and Lv Yanfang, Xiang Yun, and Wang Dong (2024) have studied the impact on the global value chain division position of China's manufacturing industry from the perspective of trade networks; Chen Shaowei et al. (2018) showed that the improvement of trade network status can enhance the country's control over core resources and promote economic development. Xu Chaokai et al. (2023) used eigenvector centrality as a proxy variable for trade network status to study the impact of trade status on product export resilience. Li Huaizheng et al. (2024) found that the development of technology finance has a significant impact on the digital service trade network position of the industry. Shang Hui et al. (2022), Mao Qilin et al. (2024), Yang Yang et al. (2024), and Chen Yuan et al. (2024) believe that the improvement of innovation efficiency is the main driving force to promote the rise of a country's trade network status; Mi Jun et al. (2024) used the random actor-oriented model to study the cross-network effects between the digital trade rule network and the digital service trade network.

The research on trade networks and their impact on economic development is extensive and multifaceted. It is clear that the position within the trade network can significantly influence a country's economic prospects. The studies mentioned above provide a comprehensive view of how different factors, such as digitalization and innovation efficiency, can affect a nation's standing in the global trade network.

2.2 Research on Industry Digitalization Level

In recent years, the digital economy, primarily driven by artificial intelligence and digitalization, has been continuously developing. The level of industry digitalization has become a key factor in determining the strength of a country's international competitiveness. Wu Youqun et al. (2022) found that the level of digitalization can significantly enhance the competitiveness of industries in the global value chain. Li Yong and Zhu Siyu (2024) discovered that the rapid development of ICT service trade is becoming a "new driving force" in promoting the division of labor status of China's manufacturing industry in the global value chain. Lv Yue et al. (2023), through the study of the artificial intelligence industry, found that the rapid development of a country's AI industry can enhance the country's value chain competitiveness.

Li An et al. (2023) and Gao Panfeng et al. (2024) believe that as the degree of industry digitalization increases, it will promote technological innovation, thereby enhancing China's international competitiveness. Liu Bai et al. (2023), based on the changes in corporate asset structure, found that as digitalization deepens, companies will show characteristics of "dermatosis to reality". Huang Yuxia et al. (2024), based on data from the World Input-Output Database, found that the degree of digitalization will significantly promote the increase of domestic added value in a country's exports, but there is heterogeneity in the promoting effect between digital hardware and digital software. Xue Tianhang et al. (2024) found that trade digitalization and manufacturing serviceization have a positive interactive effect on the added value rate of manufacturing intermediates. Huang Xiangzhong and Huang Qichai (2023) and Zhang Tianshuo et al. (2024) found that the improvement of digitalization level can optimize resource allocation efficiency and reduce trade costs, thereby enhancing the centrality of manufacturing in the trade network. Zhang Qing and Yu Pingjin (2024) and Fang Hui et al. (2024) confirmed through the measurement of the digital input level of manufacturing that the level of industry digitalization can promote the high-end leap in the global value chain of manufacturing.

2.3 Literature Review

Based on the above literature analysis, the current scholars' analysis of trade networks mainly focuses on the characteristics of trade networks and the impact of network status. Although some articles consider what factors may affect the status of trade networks, most scholars only consider the endowment characteristics of the research object itself from the perspective of the traditional gravity model, and do not take into account digital factors, etc. Therefore, the marginal contributions of this paper are: Constructing a trade network with added value as the weight, since added value can more accurately reflect the actual contribution of the trading country and can accurately measure the real status of foreign trade in the economy, using added value as the weight can better describe the specific characteristics of the trade network studied; Starting from the perspective of industry digitalization, studying the impact of emerging factors on trade network status, which has certain theoretical and practical significance.

The development of the digital economy and its impact on the real economy have been widely discussed. The integration of digital technology with traditional industries is seen as a key pathway for enhancing productivity and efficiency across various sectors . The digital economy is recognized as a new engine for driving resource allocation within enterprises, and a rational asset structure is considered a necessary condition for achieving high-quality development. The advancement of digital economy levels has been shown to significantly promote the expansion of a country's participation in global value chains, primarily by enhancing productivity and reducing external transaction costs. Furthermore, the digital economy is also seen as a catalyst for innovation, with digital service trade networks playing a significant role in the global value creation and distribution. The integration of digital technologies is expected to foster more production stages and improve the position of firms within the global production line. These discussions highlight the importance of digitalization in shaping the competitive landscape of industries within the international trade network.

3 Network Feature Construction and Feature Fact Analysis

3.1 Construction of the Manufacturing Trade Network

Based on the method of Social Network Analysis (SNA), the economic entities involved in the trade of manufacturing value-added are taken as nodes, and the value-added trade flows between economies are used to depict the value-added trade connections between nodes, thereby constructing the manufacturing value-added trade network.

To reflect the specific position of a country's manufacturing industry in the international trade network, this paper selects 44 countries from the WIOD (2016 edition) database as the research objects to construct an international trade network. The specific approach is to take each country as a network node, the trade relationship between two countries as an edge, and the value-added trade volume in manufacturing between two countries as the weight to construct a directed weighted trade network. Following the treatment methods of Fagiolo et al. (1988) and Xing Xiaobing et al. (2024), the vector A = [a_1, a_2 ... a_n] represents the exporting countries, and E = [e_1, e_2 ... e_m] represents the importing countries. An adjacency matrix V = $[v_{i,j}]_{n\times n}$ is used to describe the unweighted trade network, reflecting the trade relationship between two countries; when there is trade between two countries, vi,j = 1, otherwise vi,j = 0. A weighted matrix W = $[w_{ij}]_{n\times n}$ is used to represent the trade volume between two countries. Thus, the manufacturing trade network matrix G = (A, E, V).

Since there are widespread economic connections in the value-added trade among the manufacturing sectors involved between the 44 economies in the WIOD data, to more clearly represent the characteristics of the manufacturing trade network, this paper refers to the method of Cui Yan and Fu Chen (2024) and selects \$1 million as the threshold for the export of value-added trade between two countries, treating this threshold as the directed weight of the bilateral value-added trade network. Furthermore, through binary processing, if the value-added trade export value between two countries is greater than or equal to \$1 million, then there is a significant value-added trade relationship between the two countries, which is set to 1; if it is less than \$1 million, it is set to 0. For this, the following functional form will be used.

$$Value_{ijt} = \{^{0,VAX_{ijt}<1}_{1,VAX_{ijt}>1}$$

The trade network data constructed in this paper comes from the UIBE GVC database of the University of International Business and Economics. Referring to the United Nations International Standard Industrial Classification, 4th Edition (ISIC_Rev_4), and following the approach of Huang Yuxiang and Xie Jianguo (2020), all 18 sub-industries of manufacturing, namely entries C05-C22, are selected as the research objects. Based on the threshold mentioned above, the trade network is processed using Ucinet software with a 0-1 treatment to construct the manufacturing trade network.

3.2 Topological Analysis of the Manufacturing Trade Network

This paper utilizes Gephi software for the visualization analysis of the manufacturing trade network, with the results shown in Figure 1. In the figure, the nodes represent countries in the WIOD, and the edges between countries represent the value-added trade volumes between them, with larger volumes corresponding to thicker edges. It can be observed from the figure that the manufacturing trade network has a distinct "core-periphery" structure. Among them, the United States, China, Germany, Canada, Japan, Italy, and other countries have prominent value-added trade volumes, indicating that these countries hold a primary position in the manufacturing trade network.

Table 1 Summary of Overall Manufacturing Trade Network Indicators

year	NodeCount	Edges	Average Degree	Network Density	Average Clustering Coefficient	Network Diameter	Average Path Length
2000	43	1714	39.86	0.949	0.962	2	1.05
2001	43	1716	39.91	0.95	0.963	2	1.049
2002	43	1731	40.26	0.958	0.969	2	1.041
2003	43	1747	40.63	0.967	0.975	2	1.033
2004	43	1765	41.05	0.977	0.982	2	1.023
2005	43	1772	41.21	0.981	0.985	2	1.019
2006	43	1776	41.30	0.983	0.988	2	1.017
2007	43	1787	41.56	0.989	0.991	2	1.011
2008	43	1787	41.56	0.989	0.991	2	1.011
2009	43	1779	41.37	0.985	0.987	2	1.015
2010	43	1782	41.44	0.988	0.989	2	1.013
2011	43	1789	41.60	0.991	0.992	2	1.009
2012	43	1786	41.53	0.989	0.990	2	1.011
2013	43	1789	41.60	0.991	0.992	2	1.009
2014	43	1789	41.60	0.991	0.992	2	1.009

Note: Average Degree (deg) = (In-degree + Out-degree)/2; the above data is based on the UIBE database and calculated using Ucinet software.

3.3 Quantitative Model, Measurement Indicators, and Data Processing

3.3.1 Quantitative Model

Based on the literature reviewed, this paper sets up the following baseline model:

$$Degree_{ijt}=\alpha_0+\alpha_1 Digital_{ijt}+\alpha_2 X+\Phi_i+\Phi_j+\Phi_t+\varepsilon_{ijt}$$

i, j, and t represent the country, industry, and year, respectively.

Degreeijt indicates the position of industry j in country i in year t within the manufacturing trade network.

Digitalijt represents the level of digitalization of industry j in country i in year t.

Xijt includes control variables at the industry level: industry scale (Scale), labor compensation (Lab), industry capital stock (Cap), and industry competitiveness (HHI), as well as control variables at the country level: educational investment (Edu), research and development investment (R&D), foreign direct investment ratio (FDI), and per capita gross domestic product (avGDP).

Φi,Φj, and Φt denote the fixed effects for countries, industries, and time, respectively.

ε_{ijt} is the error term.

3.3.2 Measurement of Core Indicators

Digitalization Level of Input (Digital). This paper refers to the method of Zhang Qing and Yu Pingjin (2021), comparing the WIOD data with the industry code and the "Statistical Classification of the Digital Economy and its Core Industries (2017 Edition)". Industries C26, J61, and J62-63 are selected as the main sources of industry digital input. Eighteen manufacturing sub-industries such as C05-C22 are selected as the research objects.

Referring to Xu He Lian et al. (2017), the input-output method is used to measure the digitalization level of the manufacturing industry. The specific indicators are direct consumption coefficient, complete consumption coefficient, direct dependency, and complete dependency. The direct consumption coefficient (DC^d) reflects the amount of intermediate product inputs directly consumed by other departments to generate a unit of final product of a department; the complete consumption coefficient (DC^c) can be obtained from the direct consumption coefficient. The calculation formula is:

$$DC^c_{dj}=a_{dj}+\sum_{m=1}^{N}a_{dm}a_{mj}+\sum_{l=1}^{N}a_{dl}a_{lm}a_{mj}+\cdots$$

In the formula, a_{dj} represents the direct consumption coefficient of department j for department d. The second term is the first indirect consumption coefficient of department j for department d through department m, and all subsequent terms follow similarly. Thus, each element forms the complete consumption coefficient matrix$DC^c=D+D^2+\cdots+D^m=(E-D)^{-1}-E$.

Based on the above method, following the approach of Zhang Qing and Yu Pingjin (2021), and Fang Hui et al. (2024), the complete dependency ratio (DRjt) of the manufacturing industry on the digital sector is used to measure the digitalization level of the manufacturing industry in various countries. The formula is as follows:

$$DR_{jt}=\sum_{d=1}^{M}\left(complete_{dj}\Big/\sum_{N=1}^{N}complete_{nj}\right)$$

where M and N represent the number of digital sectors and the number of all other sectors, respectively. $complete_{dj}$ represents the complete consumption coefficient of the manufacturing sector on the digital sector, and $complete_{nj}$ represents the complete consumption coefficient of the manufacturing sector on all other sectors.

Manufacturing Trade Network Position (Degree). Research on trade network positions is mostly based on topological analysis. This paper selects the average degree of the manufacturing trade network to represent the position of a country's industry in the international trade network.

3.3.3 Data Processing

The original data for the dependent variable in the above model comes from the WIOD (2016 edition) database, excluding Taiwan and the rest of the world as two statistical dimensions. When calculating the final results, data with a negative digitalization level are set to zero. The data for the dependent variable, the position in the manufacturing trade network, comes from the UIBE GVC database, which is binarized using Ucinet software, and then a trade network is constructed for measurement.

For the industry-level control variables, data on industry scale (Scale), labor compensation (Lab), and industry capital stock (Cap) also come from the WIOD SEA database, and logarithms are taken. The country-level control variables include education expenditure (Edu), research and development expenditure (R&D), foreign direct investment share (FDI), and per capita national income level (avGDP), with the above data coming from the WDI database. After processing and merging the above data, a panel data set of value-added trade networks between 42 countries and 18 sub-manufacturing industries was finally organized, with a total of 11,340 observations.

3.3.4 Basic Regression

Based on the benchmark model, a regression analysis was conducted on the relationship between the digitalization level of the manufacturing industry and its position in the manufacturing trade network. The results are presented in Table 1. Column (1) of Table 1 uses the core explanatory variable for direct regression. The results show that the digitalization level of a country's industry significantly affects the industry's position in the international trade network. Columns (2) and (3) of Table 1 sequentially add industry-level and country-level control variables. The estimated coefficient for the digitalization level remains positive and is significant at the 5% and 1% levels, respectively.

Table 2 Basic Regression Results

	(1)	(2)	(3)
	deg	deg	deg
dig	13.0487***	3.6912***	3.3852***
	(10.5391)	(3.8901)	(3.6082)
Industry Control Variables	No	Yes	Yes
Country Control Variables	No	No	Yes
Time Fixed Effects	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes
N	11340	11340	11340
adj. R^2	0.877	0.929	0.931

Note: *t* statistics in parentheses, *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

3.3.5 Robustness

To examine the robustness of the regression results, this paper conducts robustness tests by substituting the dependent variable and the core explanatory variable.

Change in the core explanatory variable. In the basic regression, the digitalization level of the manufacturing industry is measured by the complete consumption coefficient of the manufacturing industry's input to the digital sector. This paper follows the method of Fang Hui (2024) and uses the proportion of digital input in the manufacturing sector to the industry's value-added as a proxy variable for the industry's digitalization level. The regression results are shown in columns (1) and (3) of Table 2. After replacing the core explanatory variable, the digitalization level of the industry has a significant positive effect on enhancing the position of the manufacturing trade network at the 1% level.

Change in the dependent variable. The position of a country's manufacturing sector in the global trade network represents its competitiveness in the corresponding field. The higher the trade network position, the stronger its core competitiveness. Based on the research of Li An, Xu Chaokai, and Liu Hongman (2023), this paper uses the sector's eigenvector centrality (EC) to replace the original dependent variable and re-estimates the model. As shown in column (2) of Table 2, the regression results are significantly supported at the 1% level, indicating that the model has a stable explanation for the facts.

Table 3 Robustness Analysis Results

	(1)	(2)	(3)
	deg	EC	
dig	3.3852***	0.0230***	
	(3.6082)	(4.8975)	
dig1			2.3459***
			(4.2916)
Control Variables	Yes	Yes	Yes
_cons	-32.6353***	-0.1837***	-32.5579***
	(-11.7123)	(-13.1566)	(-11.6868)
Time Fixed Effects	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes
N	11340	11340	11340
adj. R^2	0.931	0.834	0.931

Note: *t* statistics in parentheses,*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

3.4 Heterogeneity Analysis

3.4.1 Country Heterogeneity

To explore the role of digitalization levels in promoting the enhancement of trade network positions in the manufacturing sectors of countries with different economic development levels, this paper classifies the 42 countries into 9 developed countries and 33 developing countries based on the standards of the World Bank and the United Nations Development Programme. The regression results are shown in columns (1) and (2) of Table 3. The increase in digitalization level significantly and positively promotes the enhancement of trade network positions in the manufacturing sectors of developing countries, while the promotion effect on developed countries is not significant.

3.4.2 Industry Heterogeneity

Following the method of Wu Yangwei and Li Xiaodan (2016), the 18 manufacturing sectors are divided into technology-intensive, labor-intensive, and capital-intensive industries to study the impact of digitalization levels on the trade network positions of different types of manufacturing industries. The specific regression results are shown in columns (3), (4), and (5) of Table 3. The digitalization level has a significant positive impact on the enhancement of trade network positions in technology-intensive sectors. The increase in digitalization level can further enhance the resource richness of technology-intensive sectors, thereby improving resource utilization efficiency and promoting the enhancement of trade network positions in corresponding manufacturing sectors. The impact on labor-intensive sectors is also very significant. The reason is that the increase in digitalization level promotes labor-intensive sectors to improve resource utilization efficiency, introduce advanced technology, and enhance the export complexity of products, thereby enhancing the international competitiveness of their products and promoting the rise of their international trade status. The promotion effect on capital-intensive sectors is not significant.

Table 4 Heterogeneity Analysis Results

	(1)	(2)	(3)	(4)	(5)
	Developed Countries	Developing Countries	Technology-Intensive	Labor-Intensive	Capital-Intensive
	deg	deg	deg	deg	deg
dig	2.4161	2.3889**	3.8260***	18.3720***	4.4704
	(1.4757)	(2.3707)	(3.5388)	(3.6045)	(1.0125)
Control Variables	Yes	Yes	Yes	Yes	Yes
_cons	-43.8218***	-16.9906***	-27.6438***	-42.2388***	-25.8657***
	(-4.7046)	(-5.7713)	(-5.7188)	(-8.2424)	(-6.3861)
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes
N	2430	8910	3150	2520	5670
adj. R^2	0.886	0.933	0.946	0.944	0.929

Note: t statistics in parentheses,*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

3.5 Conclusion and Policy Recommendations

Through empirical analysis, this paper reaches the following conclusions: The level of digitalization plays a promotional role in enhancing the trade network position of a country's manufacturing sector. This effect exhibits heterogeneity across different types of countries and industries, specifically showing a greater promotional effect in developing countries than in developed countries, and a greater effect on labor-intensive and technology-intensive industries than on capital-intensive industries.

Based on the above conclusions, the following policy recommendations are proposed.

First, the construction of digital infrastructure in the manufacturing industry should be strengthened to improve its levels of digitalization, networking, and intelligence. This will enhance the international competitiveness of the manufacturing industry, promote the servitization of manufacturing and the globalization of services, thereby elevating its position in the international trade network.

Second, the cultivation and introduction of digital talent should be emphasized, and the construction of a digital talent team should be strengthened to improve the digital skills and digital thinking of practitioners in digital trade-related fields.

Lastly, there should be active efforts to align with international high-standard economic and trade rules, participate in the formulation of multilateral and regional digital trade rules, and create an open, fair, just, and non-discriminatory environment for digital development.

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