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Analyzing the Impact of Digital Technology on Global Value Chain Embedding from the Perspective of Chinese Manufacturing Industry

Ze Liang*

School of Economics, Xi'an University of Finance and Economics, Xi'an, 710100, China
**Corresponding author: 1015471774@qq.com*

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Abstract: Amid the deep integration of traditional manufacturing and digital technologies, digital transformation has become a crucial strategic measure for China to overcome the "low-end lock" trap in manufacturing and optimize the value chain's restructuring. This paper employs input-output data from China's manufacturing industry between 2000 and 2014 to examine the correlation between input digitalisation level and China's manufacturing industry's embedding status and level in the global value chain. An empirical analysis using a multidimensional fixed-effect model reveals that as digital technology continues to mature, Chinese manufacturing enterprises have significantly improved their competitiveness in the global value chain, as evidenced by an elevated embedding level and status. Heterogeneity analysis indicates that high- and medium-technology manufacturing industries have benefited considerably from the digital technology development dividend, while low-technology manufacturing industries' excessive competitive advantage in labour has resulted in a decline in their international competitiveness with digital technology adoption. Mechanism tests suggest that input digitisation primarily enhances China's manufacturing industry's embedding level and status in the global value chain by reducing trade costs and enhancing innovation capacity.

1. Introduction

Since the 1980s, the world economy has been characterized by the global value chain (GVC) division of labor model, which is driven by the booming development of information and communication technologies, transportation technologies, international trade and investment, and the intensification of the global flow of production factors such as capital. China has integrated quickly into the global production network created by multinational companies from developed countries, benefiting from its low cost of land, labor, and other factors. Manufacturing trade has a low value-added rate, excessive resource consumption, and other drawbacks. Additionally, the current period of global epidemic impact, the aftermath of the financial crisis, and the emerging new technological revolution are causing accelerated reconstruction of the GVC.

The growing significance of the digital economy as a driver of economic and social progress has become increasingly evident in light of the rapid advancements and integration of digital technologies such as big data, cloud computing, and the Internet across various industries. Many nations, including China, France, India, the United States, and the European Union, have accorded utmost priority to the expansion of the digital economy, which embodies a novel approach to economic development that fosters industrial transformation and propels the present technological revolution.

This paper holds significant implications as it elucidates the impact of input digitization on China's manufacturing value chain upgrading. Through theoretical and empirical exploration of the correlation between digitization and value chain upgrading, this study offers novel insights for China's manufacturing industry to enhance competitiveness in the global market. Given the ongoing technological revolution and the growing significance of the digital economy, our findings have the potential to contribute to the sustainable growth of China's manufacturing industry and overall economic development.

2. Literature Review

By reviewing scholarly research on digitalization and global value chains (GVCs), this study has identified two distinct categories of literature that are closely related to the topic at hand.

The first type focuses on the factors influencing GVCs. From the perspective of trade costs, factors such as geographical distance, trade barriers, and information asymmetry play important roles in shaping GVCs. Reducing information costs, on the other hand, can facilitate the matching of trading parties [1]. From the perspective of innovation capacity, developed countries with stronger innovation capacity are able to invest continuously in new technologies in the production process, thus increasing the technological complexity of their products for export and expanding their international competitive advantage [2]. Developing countries, on the other hand, can narrow the technological disparity with developed countries through imitative innovation and occupy a certain share in the global distribution of labor and trade [3].

The second type of literature focuses on the developmental benefits of digitalization. Digitalization has significantly reduced trade costs. For instance, the application of intelligent logistics has considerably decreased the transportation costs of export businesses. Internet technology has lowered the communication and information costs of exporters [4]. The information-based customs clearance platform has streamlined various customs clearance procedures, thus reducing some customs clearance costs. Digitalization can enhance companies' innovation levels. Zhang et al. [5] argue that digital technology blurs the internal boundaries of firms, strengthens interdepartmental cooperation, and, in turn, promotes innovation activities.

In summary, the current literature on digitalization and GVCs has established a theoretical foundation but lacks empirical analysis and comprehensive examination of digital technology's impact on GVC participation. This study innovates by providing a systematic explanation of how digital technology promotes China's manufacturing value chain upgrading through theoretical analysis and econometric modeling. Moreover, it examines the effect of technology intensity on digital technology's impact on value chain participation in China's manufacturing industry. Furthermore, an industry-level measurement index of digitalization is constructed, and export market factors are incorporated to enhance understanding of the relationship between digital technology and GVC participation.

3. Research Hypotheses

3.1. Trade cost reduction mechanism

Trade costs refer to all expenses involved in the process of product flow from the warehouse to the consumer, including storage fees, transportation fees, tariffs, and information costs [6]. However, digital elements are highly permeable, and their applications cut across all aspects of GVC trade. On the one hand, the rise of Internet of Things (IoT) technology has led to intelligent warehouse logistics that can complete multiple processes such as storing, transporting, loading and unloading. It can also track goods, significantly reducing the cost of storing, transporting, and monitoring for enterprises. On the other hand, traditional international trade is often limited by spatial and geographic distance, while digital trade has broken this constraint by bringing the cost of moving digital products and services between countries closer to zero. This has increased data liquidity and significantly reduced the difficulty of information access, effectively alleviating the problem of adverse selection and moral hazard among subjects in the trade value chain and reducing information costs [7]. Enterprises can enhance their competitive advantage and generate greater value in export trade. This, in turn, can lead to an improved position within the GVC. Consequently, this paper puts forward Hypothesis 1:

Hypothesis 1: The integration of digital technology into China's manufacturing industry is expected to elevate its position in the GVC, as it reduces trade costs across all sectors.

3.2. Innovation capacity enhancement mechanism

Only with a certain degree of independent innovation capability, such as secondary imitation and innovation of advanced processes, can they catch up with the speed of international market updates and iterations, meet increasingly diversified external consumer demands, and cultivate original design capabilities further. The emergence of digital platforms has made it easier to share and integrate knowledge across different technological domains. By leveraging these platforms, enterprises can break away from existing technological path dependencies, accelerate independent research, and facilitate the realization of technological innovation and output transformation. This,in turn, can enhance the competitive advantages of manufacturing enterprises in areas such as product quality and pricing, promote value addition, and provide new momentum for elevating China's value chain to a higher-end level. Consequently, this paper puts forward Hypothesis 2:

Hypothesis 2: The advancement of digital technology in China's manufacturing industry has propelled it to the forefront of the GVC, by augmenting its capacity for technological innovation and improving performance through transformation.

4. Research Methodology

4.1. Variable definitions

4.1.1. The level of global value chain embedding

This paper divides value chain embedding into forward and backward components. The forward component measures a country's domestic value-added and purely double-counted intermediate goods exports to export markets and third countries as a proportion of its total exports, while the backward component measures foreign value-added and foreign purely double-counted portion originating from export markets and other economies as a proportion of its total exports. Total value chain embedding is the sum of these two ratios, which can be calculated using the following formula:

$$GVC\_Embedding = (DVA\_INT\_REX + MVA + PDC + RDV)/TEXP \qquad (1)$$

4.1.2. The status of global value chain embedding

Previous research has frequently employed the location index formulated by Koopman et al. [8] to evaluate the placement of nations within GVCs. This index employs the trade value-added structure and assesses a country's degree of value chain embedding by measuring the ratio of forward value chain embedding to backward value chain embedding. Sheng & Jing [9] have extended this index to the industry level. Based on this expansion, the GVC embedding status index is established via the subsequent equation:

$$GVC\_Embedding = ln[(1 + DVA\_INT + DVA\_INT\_REX)/TEXP] - ln[(1 + MVA + OVA)/TEXP] \quad (2)$$

In the equations (1) and (2), the symbols used refer to specific parameters. Specifically, $TEXP$ represents the aggregate quantity of products, while DVA_INT is the domestic value added of intermediate exports that are absorbed by countries that directly import the products. DVA_INT_REX denotes the share of domestic value added of intermediary goods that are exported to one market and then subsequently re-exported to third-party countries. MVA refers to the value added by importing nations through their exports. OVA represents the added value of other countries implied by the exports. PDC denotes pure double counting of the intermediate trade goods component. Finally, RDV represents the value added that returns to the country.

4.1.3. Digitization inputs (DI)

This article examines the methodologies used by scholars to evaluate the degree of digitalization of input services, drawing from works by Yang Ling [10], and applies them to gauge the extent of digitalization of input in China's manufacturing industry. Specifically, this study employs pertinent data on China's manufacturing industry's export market, as provided by the World Input-Output Database (WIOD 2016), and defines the degree of digitalization of input in a given manufacturing sector as the proportion of intermediate input from highly digitized sectors in that sector's total input. The high highly digitized sector is defined as "C26 Computer, electronic and optical products manufacturing," "J61 Telecommunication industry," and "J62-63 Computer programming, consulting and information service activities," based on the table of the division of industries dependent on the digital economy listed by Zhang Qing[11].

In this model, the complete consumption coefficient method is utilized to measure the level of input digitization. This method takes into account indirect inputs from different sectors and incorporates them into the measurement system. The formula used for calculation is as follows:

$$DI_{ij}^{complete} = \alpha_{ij} + \sum_{k=1}^{n} \alpha_{ik}\alpha_{kj} + \sum_{s=1}^{n}\sum_{k=1}^{n} \alpha_{is}\alpha_{sk}\alpha_{kj} + \cdots \quad (3)$$

where, $DI_{ij}^{complete}$ denotes the level of input digitization in the manufacturing sector j as measured by the full consumption coefficient method. α_{ij} is actually the direct consumption in equation (2). $\sum_{k=1}^{n} \alpha_{ik}\alpha_{kj}$ denotes the corresponding first indirect consumption,$\sum_{s=1}^{n}\sum_{k=1}^{n} \alpha_{is}\alpha_{sk}\alpha_{kj}$ denotes the corresponding second indirect consumption, The omitted item n+1 indicates the nth indirect consumption.

4.1.4. Control Variables

①Intermediate Inputs (Inter-input): the level of intermediate consumption within an industry is used to measure the intermediate consumption of a country. ②Industry Size (Size): the average annual number of employees in an industry is used to represent the size of the industry. ③Research and Development (R&D) Expenditures. ④Labor Productivity (Pro). ⑤Export Scale (Exscale).

4.2. Model Settings

This paper aims to examine the influence of input digitization on the integration of China's manufacturing industry in the GVC. To achieve this objective, an econometric model is formulated and presented below:

$$GVC\_Embedding_{ijt} = \alpha_0 + \alpha DI_{it} + \alpha_1 \sum Control + \mu_i + \mu_j + \mu_t + \varepsilon_{ijt} \qquad (4)$$

where i represents the manufacturing industry, j represents the dxport market, t represents the year; $GVC\_Embedding_{ijt}$ as the explanatory variable of this paper denotes the embedding level and embedding status of China's manufacturing sector in the GVC;α_0 denotes a constant term;DI_{it} as the core explanatory variable of this paper denotes the level of input digitization in China's manufacturing sector;$\sum Control$ denotes control variables;μ_i, μ_j and μ_t respectively denote controls for industry fixed effects, time and export market fixed effects;ε_{ijt} denotes the random disturbance term of the model. In addition, to reduce heteroskedasticity, the control variables are logarithmized in this paper (except for the ratio variables).

4.3. Data Sources

This article draws on data sourced from the World Input-Output Database 2016, which captures information pertaining to the digitization of manufacturing inputs and GVC embedding indicators. In addition, data on intermediate inputs, industry size, R&D expenditure, labor productivity, and export size were obtained from the China Industrial Statistical Yearbook. Our analysis is focused exclusively on the manufacturing sector.

4.4. Descriptive Analysis

This study utilizes data pertaining to 17 manufacturing sectors in China, for the time frame of 2000-2014, across 42 export markets, culminating in a dataset comprising 10,710 observations. The primary variables' descriptive statistics are exhibited in Table 1.

Table 1: Descriptive statistics of main variables

Variables	Observations	Mean	Std.Dev	Minimun	Maximum
Embedding level	10710	0.2446	0.1777	0.0010	0.8800
Embedding status	10710	0.2465	0.1813	-0.2875	0.6096
DI	10710	0.0044	0.0159	0.0000	0.2930
Pro	10710	9.9500	0.9200	6.7100	11.4300
Size	10710	5.6342	0.8106	3.9128	7.3272
R&D	10710	13.7199	1.5436	9.2163	16.4492
Inter-input	10710	13.2781	1.0771	8.0624	16.4780
Exscale	10710	11.502	1.347	5.019	9.081

5. Empirical Analysis

5.1. Benchmark regression

This paper employs a multidimensional fixed effects model to estimate equation (1) and presents the results in Table 2. The first two columns of the regression control for time fixed effects only. The estimated coefficients indicate that the key explanatory variables of digitalizing manufacturing inputs have a positive and significant effect at the 1% level, which is consistent with our expectations. Columns (3) to (4) include additional fixed effects for industry, time, and export market to ensure robustness. The positive and significant coefficient of digitalization of manufacturing inputs reinforces our conclusion that China's digital technology development has enhanced the competitiveness of its manufacturing firms in the GVC, as demonstrated by the significant improvement of the embedding level and status of the value chain.

Table 2: Benchmark regression results

Variables	(1) Embedding level	(2) Embedding status	(3) Embedding level	(4) Embedding status
DI	1.6619***	2.1181***	0.9057***	1.3827***
	(20.0378)	(25.9497)	(13.3683)	(21.0122)
Pro	0.0334***	0.0328***	0.0330***	0.0290***
	(24.5173)	(24.5293)	(5.8244)	(5.2640)
Size	-0.0308***	-0.0148**	-0.0150***	0.0005
	(-4.4295)	(-2.1623)	(-2.7223)	(0.1011)
Exscale	-0.0052	-0.0336***	-0.0039	-0.0322***
	(-0.8694)	(-5.6782)	(-0.8134)	(-6.9769)
R&D	0.0021	0.0086**	0.0050	0.0114***
	0.5504)	(2.2530)	(1.6085)	(3.7957)
Inter-input	0.0007***	-0.0009***	0.0006***	-0.0010***
	(3.4991)	(-4.1449)	(3.4190)	(-6.2963)
Constant	0.0039	0.0073***	0.0025	0.0059***
	(1.6355)	(3.0809)	(1.3081)	(3.1826)
Industry FE	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Export Market FE	No	No	Yes	Yes
Observations	10710	10710	10710	10710
R-squared	0.552	0.612	0.554	0.729

Note: the value within parentheses represents the t-statistic; *** ** and* represent significance levels of 1%, 5% and 10%, respectively. The same conventions apply to all tables in the following text.

5.2. Robustness analysis

To mitigate the undue influence of extreme values in control variables, such as foreign direct investment, all primary variables underwent 5% quantile trimming. The findings of this analysis are presented in columns (1) to (2) of Table 3.

The embedding level in the GVC is replaced with the GVC participation rate, which is calculated using the WWYZ method proposed by Wang et al. [12]. This indicator is comprised of forward embedding and backward embedding and is presented in columns (1) to (2) of Table 4.

The first concern is the negative coefficient of the digitization of manufacturing input in column (2), which is contrary to expectations. This is because China's forward embedding in the value chains, particularly in manufacturing, significantly outperforms its backward embedding in enhancing its major industry. This implies that the application of digital technology drives China's value chain upgrading more from a forward embedding perspective, leaving the impact of digitalization on backward embedding in the value chain for further examination.

Overall, the regression results for digitization input are positive and significantly robust, thus reaffirming the strength of the outcomes outlined in this paper.

Table 3: Robustness tests for sample data

Variables	(1) Embedding level	(2) Embedding status	(3) Forward participation	(4) Backward participation
DI	4.4030***	3.0318***	0.1169***	-0.7009***
	(24.7104)	(20.8392)	(10.7445)	(-38.3011)
Constant	0.7273***	0.9129***	0.1534***	-0.0380**
	(7.7380)	(11.8969)	(15.8498)	(-2.3371)
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Export Market FE	Yes	Yes	Yes	Yes
Observations	10710	10710	10709	10709
R-squared	0.676	0.720	0.953	0.801

5.3. Industry heterogeneity analysis

Referring to the European Union Classification of Economic Activities Standard Version 1 and the work of Yang et al. [14] on measuring the technological complexity of China's industries, this paper categorizes the 17 manufacturing sectors into three groups: high-technology-intensive industries, medium-technology-intensive industries, and low-technology-intensive industries.

Table 4 below presents the results of the regressions. The findings reveal that the regression coefficients for input digitization in high- and medium-technology-intensive industries are positive. The estimated coefficient is higher for medium-technology-intensive manufacturing industries, indicating that the adoption of digital technology has significantly boosted the competitiveness of these two manufacturing sectors in the GVC. Additionally, medium-technology-intensive industries have attained a greater level of digital integration and have profited more from digital dividends.

On the other hand, for low-technology-intensive manufacturing industries, the estimated sign of the input digitization coefficient is negative. This may be due to the dominating competitive advantage of labor factors in these industries, making it challenging to integrate digitization fully into production operations and other aspects. As a result, the digital dividend may not be adequate to offset the loss incurred by the reduction of labor allocation, resulting in higher production costs and reduced international competitiveness for this sector.

Table 4: Industry heterogeneity analysis

Variables.	Low technology-intensive industries		Medium technology-intensive industries		High technology-intensive industries	
	Embedding level	Embedding status	Embedding level	Embedding status	Embedding level	Embedding status
DI	-4.2919***	-5.3818***	22.9478***	11.6738***	0.7131***	0.9471***
	(-4.0702)	(-4.4918)	(13.1929)	(8.6615)	(6.8575)	(8.6578)
Constant	0.5912***	0.8041***	-0.2622***	0.5659***	0.3854***	2.3112***
	(19.3075)	(23.1088)	(-6.3996)	(17.8281)	(4.8352)	(29.1951)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Export Market FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3780	3780	3150	3150	3780	3780
R-squared	0.458	0.598	0.615	0.304	0.474	0.410

5.4. Mechanism Test

5.4.1. Mechanism test of trade cost reduction

To measure the cost of international trade, Novy [14] integrated iceberg transportation costs into the gravity model, based on the monopolistic competition framework, which is set up as follows:

$$\tau_{ij} = 1 - [EXP_{ij}EXP_{ji}(GDP_j - EXP_j)(GDP_i - EXP_i)s_i s_j]^{\frac{1}{2\rho-2}} \tag{5}$$

Where, the trade cost of country i to country j is represented by τ_{ij}. The total exports of country i and j are denoted as EXP_i and EXP_j, respectively. Moreover, the total exports from country i to country j and the total exports from country j to country i are represented by EXP_{ij} and EXP_{ji}, respectively. Additionally, the GDP of country i and j are represented by GDP_i and GDP_j, respectively, and the share of tradable goods in each country is represented by s_i and s_j. The elasticity of substitution is denoted by ρ. This paper follows the uniform treatment of Shi Bing zhan [15] and sets s_i=s_j=0.8 and ρ=8.

The paper incorporates an interaction term between digitization inputs and bilateral trade costs to investigate the impact of digitization on a country's competitiveness in the GVC. The estimation results, displayed in Table 5, indicate that the regression coefficients of the interaction terms in columns (1)~(4) are statistically significant at the 1% level and negative, as anticipated. These findings demonstrate that digital technology has facilitated the reduction of trade costs, thereby promoting the deepening of a country's embedding level in the GVC and improving its overall embedding status.

$$GVC\_Embedding_{ijt} = \alpha_0 + \alpha DI_{it} + \alpha_1 DI_{it} \times TC_{it} + \alpha_2 \sum Control + \mu_i + \mu_j + \mu_t + \varepsilon_{ijt} \tag{6}$$

Table 5: Mechanism test for trade cost reduction

Variables	(1) Embedding level	(2) Embedding status	(3) Embedding level	(4) Embedding status
DI	4.6148***	4.6867***	2.9699***	2.8652***
	(10.0680)	(10.2055)	(8.1929)	(7.9512)
TC	-0.6134***	-0.5804***	-0.4576***	-0.4378***
	(-10.9573)	(-10.3037)	(-10.3350)	(-9.9053)
DI ×TC	-5.9539***	-5.9942***	-3.1097***	-2.9899***
	(-6.7310)	(-6.7857)	(-4.4453)	(-4.3136)
Controls	No	Yes	No	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Export Market FE	Yes	Yes	Yes	Yes
Observations	10710	10710	10605	10605
R-squared	0.677	0.678	0.655	0.661

Mechanism test for innovation capacity enhancement

The literature has often used the number of granted patents, R&D investment, and new product output value to measure innovation. However, due to the inconsistent statistical caliber of some patent data and missing R&D investment data, this paper follows the research method of Wang & Rong[16] and uses the proportion of new product output value to total industry output value to measure innovation capability.

As shown in Table 6, this paper introduces the regression of the interaction term between digitization inputs and the share of new product output (NPO) to verify the mediating utility of innovation drive. The coefficients of the interaction terms in the regressions from column (1) to column (4) are all positive and significant at the 1% level, which is in line with expectations. This confirms that the deep integration of digital technology stimulates the willingness of industry players to innovate and improves the overall innovation level. This improvement in innovation capability, in turn, promotes the competitiveness of a country's manufacturing global value chain.

$$GVC\_Participation_{ijt} = \alpha_0 + \alpha DI_{it} + \alpha_1 DI_{it} \times NPO_{it} + \alpha_2 \sum Control + \mu_i + \mu_j + \mu_t + \varepsilon_{ijt} \quad (7)$$

Table 6: Mechanism test for innovation capacity enhancement

Variables	(1)	(2)	(3)	(4)
	Embedding level	Embedding level	Embedding status	Embedding status
DI	0.73190***	0.77992***	1.34858***	1.26859***
	(10.51)	(10.93)	(19.77)	(18.31)
NPO	-0.00227	-0.02913	0.01150	0.06941**
	(-0.08)	(-0.90)	(0.40)	(2.20)
DI ×NPO	0.69964***	0.68788***	0.54959***	0.62615***
	(5.36)	(5.27)	(4.30)	(4.94)
Controls	No	Yes	No	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Export Market FE	Yes	Yes	Yes	Yes
Observations	10605	10605	10605	10605

6. Conclusions and Policy Implications

6.1. Conclusions

Through the integration of traditional manufacturing and digital technology, China can improve its position in the manufacturing industry by implementing digital transformation and upgrading. This paper focuses on the Chinese manufacturing sector, collecting input-output data of the manufacturing industry in various export markets, measuring the level of digitalization input and its embedding level and position in the GVC. In terms of empirical design, this paper constructs a multidimensional fixed effects model to analyze the effect of digital input on the embedding of the manufacturing industry in the GVC and its mechanism. Our research has found the following conclusions:

Firstly, with the increasing maturity of digital technology, the competitive advantage of Chinese manufacturing participants in global division of labor and trade is continuously enhanced, specifically manifested in the improvement of the embedding level and position of enterprises in the GVC.

Secondly, digital input has improved the participation level and position of Chinese manufacturing in the GVC through two paths: reducing trade costs and enhancing innovation capabilities.

Thirdly, both high and medium technology-intensive manufacturing industries in China have benefited from the development of digital technology, while the low-technology-intensive manufacturing industry has an excessive competitive advantage in labor. The application of digital technology has instead led to a decline in its international competitiveness.

6.2. Policy implications

Firstly, in today's rapidly evolving digital landscape, China must take strategic steps to maintain its competitive edge and strengthen its position in the global digital economy. To achieve this, China should prioritize the development of a unique "Chinese model" of digital economy growth, which can enhance its international discourse on digital economy and trade. The government should play a proactive role in promoting digital transformation in infrastructure construction by investing in advanced digital technologies.

Secondly, the government should focus on developing international e-commerce networks and improving the efficiency of intelligent logistics. By investing in advanced digital logistics technologies, such as real-time monitoring and predictive analytics, China can gradually mitigate the pandemic's impact on its economy and restore its competitiveness in global trade. To achieve this, China must establish an intelligent logistics network and promote the digital upgrade of port trade. The government should carry out pilot projects on the digitization of port trade and allocate more funding to digital elements in port construction.

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