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Article

Reinventing the Global Services Value Chain under the Wave of Digitization: An Analysis Based on Nonlinear Regression Models

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Abstract: Under the impact of digitalization wave, it is both a challenge and an opportunity for the global service industry value chain. Combined with the current development status of digital economy, it is proposed to use the entropy weight method to obtain the value of the development level of the former digital economy, while the value of the global services value chain is obtained by the trade value added method. The research variables are set, the data sources are determined, and the influence relationship between the two is explored using a nonlinear regression model. There is a significant positive correlation between the level of digital economy development and the status index of the global services value chain, and the status index of the global services value chain rises by 0.042 units for every unit increase in the level of digital economy development, which shows the interaction between the two, and provides guidance and reference for the reengineering of the value chain of the global services industry under the wave of digitization.

Keywords: nonlinear regression model; entropy weight method; trade value added method; service industry value chain

1. Introduction

In the era of digital transformation, digital technology, as a disruptive technology driving the next wave of technological revolution and industrial transformation, has not only altered the way elements are combined in corporate production processes but has also reshaped the global value chain (GVC) participation landscape at the regional and national levels, thereby redefining international trade rules [1-3].

Since the outbreak of the global financial crisis in 2008, the process of economic globalization has slowed, but the value contribution of services trade in international trade has continued to rise, becoming a key driver of global economic development [4-5]. As numerous countries have signed regional trade agreements incorporating provisions on deep services trade, the openness of the services sector has significantly increased, effectively promoting the cross-border flow of global services trade [6-7]. As globalization-driven division of labor deepens, manufacturing-centric GVCs are expanding, with the service sector emerging as a new engine for value chain upgrading [8]. Concurrently, the liberalization of services trade has accelerated the separation of services and manufacturing, giving rise to international outsourcing activities in emerging productive services such as computer and electronic communications technology and business services, while enhancing the scale and specialization of service activities and promoting structural upgrading [9-11]. The safety and stability of the service sector GVC directly impact the smooth operation of manufacturing supply chains. For example, the GVCs of computer and communications services and logistics and transportation are directly linked to the smooth operation of manufacturing supply chains [12-13]. Leveraging its advantages of high value-added and strong economic multiplier effects, the service sector is increasingly becoming a key factor in driving future industrial chain upgrades. Currently, within the GVC division of labor system, due to constraints such as labor force levels and industrial structure endowments, developing economies primarily engage in low-value-added activities within the global services value chain system, facing the long-term risk of being locked into the lower end of the value chain [14-15].

With the development of global digitalization, the global value chain in the service sector is also expanding. Digital service trade is more than twice that of non-digital service trade, with artificial intelligence customer service handling more than 40% of services and blockchain-supported cross-border services skyrocketing, continuously shortening service response times and improving service security [16-18]. The global expansion of high-end service industries such as digital financial services, information technology services, and research and development design services is becoming increasingly evident. For example, the software outsourcing industry has taken on a significant portion of global software programming and testing services, providing information technology support to numerous companies worldwide [19-21]. However, GVCs are not static. In recent years, they have faced numerous challenges and transformative factors, with a trend toward restructuring gradually emerging [22]. Literature [23] utilized an intermediary effect model and system generalized method of moments estimation to analyze the promotional value of the digital economy on China's service sector GVC, driving its GVC upgrading, though differences emerged across distinct service targets. Literature [24] proposed that to accelerate the digital transformation of the banking services value chain, projects involving infrastructure, development, and business-related information technology should be implemented to fully leverage the integration of services and digital capabilities. Literature [25] mentions that digital trade has elevated the status of transportation and warehousing services within GVCs, mediating this effect through industrial structure upgrading. Literature [26] points out that China's digital GVC status remains relatively low, but its digital value has shifted from input-driven to output-driven, with other countries participating in this value-driven process through simple service trade. Literature [27] found that the participation of African countries in the value chains of the services sector and two other industry sectors can worsen the environment, while digitalization and industry structural transformation can promote the participation of the services sector in value chains, thereby improving environmental quality. Literature [28] empirically analyzes the role of industrial internet platforms in manufacturing GVCs. Platforms act as service providers/intermediaries, enabling enterprises to derive benefits from data. Under the deepening trend of oligopoly, this service relationship faces restructuring. In the current digital age, GVC restructuring has become a key issue in the global economic landscape, profoundly influencing the economic development and international competitiveness of countries [29].

However, the academic community has not yet conducted extensive research on the restructuring of global value chains (GVCs) in the service industry driven by digitalization. Under the digital wave, the ability to accurately seize the historical opportunity of GVC restructuring and enhance the development level of the service industry will directly impact industrial transformation and upgrading. Nonlinear regression models utilize mathematical models capable of describing nonlinear phenomena to fit the desired results and reflect changes in the generated parameters, thereby better adapting to various complex data relationships [30]. Nonlinear regression models provide support for the analysis of GVC restructuring in the digitally driven service industry.

This paper takes the status quo of digital economy development as the entry point, constructs the evaluation index system of digital economy development level, and calculates the numerical value of digital economy development level by using entropy weight method, which is set as the explanatory variable to facilitate the following research work. Subsequently, under the trade value added method, the value of the global services value chain research is obtained, which will be named as an explanatory variable, while the control variables are GVC participation index (GVCpar), outward foreign direct investment (OFDI), labor cost (WAGE), and infrastructure construction (INF). With the support of the research data, a nonlinear regression model is used to explore the role of the relationship between the two to provide a reference value for the reengineering of the global services value chain under the wave of digitization.

2. Exploring the Global Services Value Chain under the Wave of Digitization

2.1. Current State of Development of the Digital Economy

2.1.1. Scale of Development of the Digital Economy

The total volume of the digital economy has been increasing for several years and its status has been steadily rising. The scale of the digital economy and its share in GDP is shown in Figure 1, which shows that the scale of the digital economy is clearly on the rise, which was still 16.16 trillion yuan in 2017 and rose to 39.18 trillion yuan in 2023, an increase of 141.67% in just four years, with an average annual growth rate of 15.84%. On the other hand, the proportion of the size of the digital economy in GDP has also increased year by year, from 26.06% in 2017 to 38.53% in 2023, an increase of 12.47 percentage points, with an average annual growth rate of 6.73%, and a year-on-year increase of 2.25 percentage points in 2023. It still gained steady growth in 2023, becoming the most dynamic, innovative and widely radiating economic form at present.

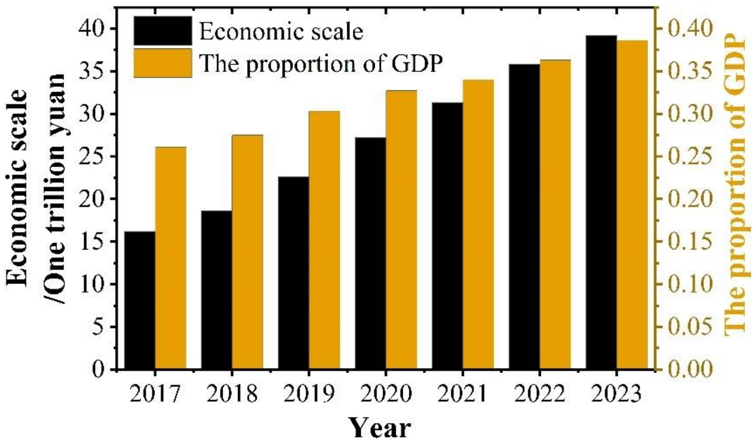

Figure 1. The scale of the digital economy and its proportion in GDP.

The digital economy has become an effective economic stabilizer under the new crown epidemic, and the comparison of the growth rate of the digital economy and GDP is shown in Figure 2, from 2017 to 2022, the growth rate of the digital economy is higher than that of the GDP, and even its growth rate is still higher than that of the GDP for the same period of time, which is even higher than the growth rate of the same period of the GDP by 6.66 percent, even in the case of the epidemic impact in 2020 and the downturn of the global economy It is evident that the digital economy has given a strong impetus to the sustained development of the economy and is a guarantee for epidemic prevention and control and economic and social development.

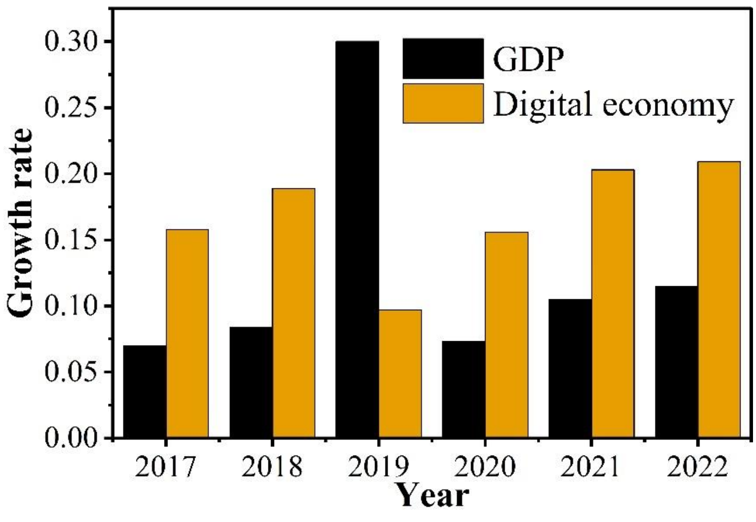

Figure 2. Comparison of the growth rate of the digital economy and GDP.

The digital development of the three major industries is thriving. The degree of influence of the digital economy on the major industries is shown in Figure 3, and it is obvious that its penetration into the service industry is the deepest, followed by industry, and the penetration into agriculture is the smallest, and during the period of 2019-2023, the digital development of the three major industries continues to advance in depth, and the penetration rate of the digital economy increases year by year, and by 2023, the share of the digital economy in the value added of the three major industries industries is 8.84%, 21.03%, 21.03%, 21.03%, 21.03%, 40.68%, or about 1:2.379:4.602, an increase of 2.685, 4.188, and 11.097 percentage points from 2019, respectively, and the digitization of industries is accelerated to participate in integrated development even further. There is still a gap with developed countries, whose penetration rates in the three major industries reached the levels of 13.26%, 33.07% and 46.66% respectively in 2022, and there is still room for improvement.

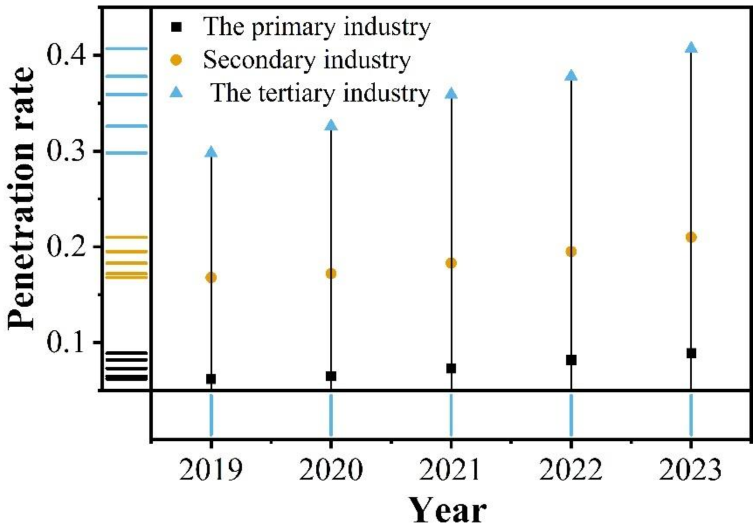

Figure 3. Digital economy penetration rate.

2.1.2. Structure of Digital Economy Development

In the 2022 Digital Economy Report, digital governance was added, expanded into three parts, and in 2023, data valorization was added, completing the development from "two modernizations" to "three modernizations" and then to "four modernizations". In terms of internal structure, the dominance of industrial digitalization in the digital economy is more significant. First of all, digital industrialization specifically refers to the telecommunications industry, electronic information manufacturing industry, Internet industry, software and information technology service industry, etc., and many emerging digital technology-related enterprises are developing rapidly, promoting the development of digital-related industries to achieve better improvement and move towards the upstream of the global industrial chain. Its total volume will be 7.47 trillion yuan in 2023, accounting for 7.26% of GDP, and Figure 4 shows the internal structure of the digital economy, which decreased from 25.66% to 19.07% between 2018 and 2023. Secondly, industrial digitalization refers to the use of digital technology to increase the benefits of traditional industries, that is, the marginal contribution of digital technology in agriculture, industry, and service industries, which has gained huge development space with the development of many new models that have emerged in recent years, such as the sharing economy, which has been very hot in recent years. In 2023, the scale of industrial digitalization will reach 31.68 trillion yuan, accounting for 31.15% of GDP. Between 2018 and 2023, it rises from 74.24% to 80.88%. Digital governance refers to a kind of "combination of technology and management", that is, represented by "digital technology governance", as well as digital public services, including but not limited to pluralistic governance. At present, the digital transformation of governance objects is accelerating, individuals form digital portraits through electronic certificates and health codes, and enterprises achieve digital operations through industrial digitization and digital industrialization, making government services and social governance must be digitally transformed.

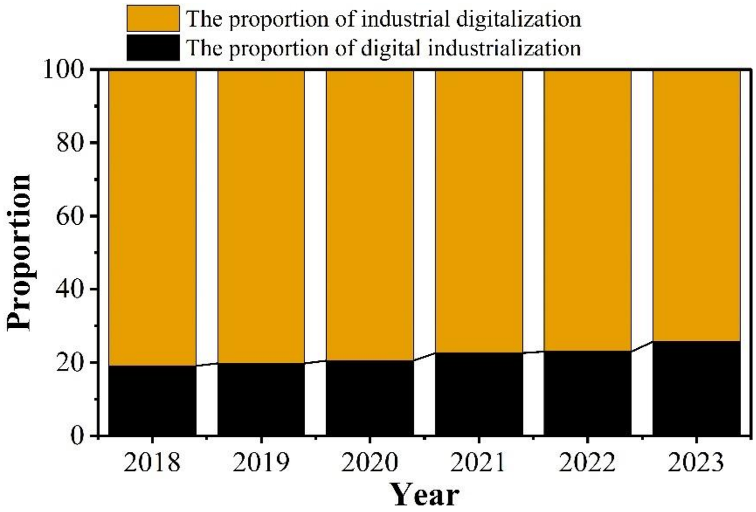

Figure 4. The internal structure of the digital economy.

2.1.3. Digital Economy Development Model

(1) Gradient development model

Because the degree of economic development and industrial structure is different in different places, the degree of embeddedness of the digital economy in the real economy and the degree of development of the digital economy are different, according to the degree of its development, the digital economy can be divided into three gradients: high, medium and low.

(2) Regional Polar Core Model

This model, as its name suggests, is a model in which a developed city with a digital economy is used as a growth pole, which subsequently generates a radiation-driven effect on the surrounding areas. Initially, there will be a siphon effect, but as the city's digital economy develops to a certain extent, it will have a diffusion and radiation effect, leading to the overall development of the surrounding area.

(3) Point-axis development model

With the development of the regional pole core model, the growth poles through economic exchanges and linked together into the form of several axes. Divided into two modes, one is geospatial connection type, and the other is virtual space connection type.

(4) Multi-level network model

This model is formed by the increase and density of growth poles, and then become a network-like structure, the existence of multiple growth poles in the region in the spatial or industrial correlation. Multi-level network model can make the “poles” with different levels and functions to carry out division of labor and cooperation to form a good regional economic ecosystem.

2.2. Measurement of the Level of Development of the Digital Economy

2.2.1. Indicator System for Evaluating the Level of Development of the digital Economy

Since there is no uniform measurement method for the digital economy, this paper utilizes the objective empowerment method to construct the digital economy development index system with reference to several major industries included in the digital economy. According to the “Statistical Classification of the Digital Economy and Its Core Industries” and the “Classification of the National Economy by Industry” issued by the National Bureau of Statistics, and by drawing on the relevant literature on the construction of the index system of the digital economy measurement ideas, the level of digital economy development will be Measurement indicator system is divided into 4 first-level indicators and 15 second-level indicators, and the evaluation indicator system of digital economy development level is shown in Table 1.

Table 1. Evaluation index system.

First-level indicator	Symbol	Secondary indicators	Symbol	Unit
Digital product manufacturing industry	X1	The number of enterprises in the computer, communication and other electronic equipment manufacturing industry	X11	Pcs
		The total profit of enterprises in the computer, communication and other electronic equipment manufacturing industry	X12	One hundred million yuan
		The average number of employees in enterprises manufacturing computer, communication and other electronic equipment	X13	Ten thousand people
Digital product service industry	X2	Sales of wholesale goods of computers, software and auxiliary equipment	X21	One hundred million yuan
		Retail sales of computers, software and auxiliary equipment	X22	One hundred million yuan
		Retail sales of communication equipment	X23	One hundred million yuan
Digital technology application industry	X3	Software business revenue	X31	One hundred million yuan
		The number of enterprises in the information transmission, software and information technology services industry	X32	Pcs
		Total volume of telecommunication services	X33	One hundred million yuan
		Mobile Internet access traffic	X34	Billion GB
Digital elements drive industries	X4	E-commerce sales volume	X41	One hundred million yuan
		The number of enterprises engaged in e-commerce transaction activities	X42	Pcs
		The number of audio-visual products and electronic publications published	X43	One million copies
		Production time of radio and television programs	X44	Thousands of hours
		Internet broadband access users	X45	Ten thousand households"

2.2.2. Entropy Weight Method

(1) Data standardization

The standardized processing method is as follows:

$$Y_{ij} = \frac{x_{ij} - \min\left(x_{ij}\right)}{\max\left(x_{ij}\right) - \min\left(x_{ij}\right)} \tag{1}$$

x_{ij} represents the j th indicator of the i th year, and Y_{ij} represents the standardized data indicators [31-32].

(2) Weight calculation

Calculate P_{ij}, the weight of the j th indicator in year i:

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \tag{2}$$

Calculate the entropy value e_j for the j th indicator:

$$e_j = -\frac{\sum_{i=1}^{n} P_{ij} \ln\left(P_{ij}\right)}{\ln(n)} \tag{3}$$

Calculate the weight of each indicator ω_{ij} :

$$\omega_{ij} = \frac{1-e_j}{\sum_{j=1}^{m} 1-e_j} \tag{4}$$

(3) Formula for calculating the level of development of the digital economy

$$Q = \sum_{j=1}^{m} w_{ij} P_{ij} \tag{5}$$

To facilitate subsequent modeling, the following formula was used to calculate the level of digital economy development in the country's service sector:

$$DE_i = \frac{IOV_i}{MOV_i} Q_i \tag{6}$$

where IOV_i represents the total output value of service industry sub-sectors in year i , MOV_i represents the total output value of service industry in year i , Q_i is the level of digital economy development in year i of the table, and DE_i is the level of digital economy development of service industry sub-sectors in year i .

In terms of global value chain accounting, scholars at home and abroad start from different dimensions to measure the global value chain division of labor status index, and the trade value added method is the most commonly used by scholars. Based on the trade decomposition framework, this paper selects the data from ADB-MRIO database, proposes the global value chain status index and participation index, and the global service industry value chain is measured comprehensively.

2.3. Global Services Value Chain Measurement

2.3.1. GVC Status Index

$$GVC_{positionir} = \ln\left(1+\frac{IV_{ir}}{E_{ir}}\right) - \ln\left(1+\frac{FV_{ir}}{E_{ir}}\right) \tag{7}$$

IV_{ir} represents indirect value added exports of the r industry in the year i , i.e. domestic value added in the form of intermediate goods produced and processed in the importing country and exported to a third country and absorbed. FV_{ir} represents the value added of exports of products of the r industry in the year i which belongs to foreign countries. E_{ir} denotes the value added of total exports of the i industry in the year r . It indicates that the country's industry is in the downstream segment of the global value chain, and the GVC status index is directly proportional to the level of the r -year i industry's position in the global value chain.

2.3.2. GVC Participation Index

$$GVC_{participationir} = \frac{IV_{ir}}{E_{ir}} + \frac{FV_{ir}}{E_{ir}} \tag{8}$$

where $IV_{i/} / E_{ir}$ is the forward participation index of the GVC, a higher index indicates that the r -year i industry participates in the division of labor in GVCs in the form of exporting intermediate products and is in the relatively upstream part of the GVCs. FV_{ir} / E_{ir} is the backward participation index of GVC, and a higher index indicates that the export of final products of the r -year i industry relies on the import of intermediate products from other countries to participate in the division of labor in the global value chain, and is in the relatively downstream part of the global value chain.

2.4. Construction of Nonlinear Regression Models

2.4.1. Introduction to the Model

Regression analysis is a scientific method developed on the basis of probability theory and mathematical statistics, is an important branch of the application of quantitative analysis techniques to study the problem, is to explore a set of statistical relationships (or correlations) between the dependent variable and the independent variable is composed of techniques [33].

The theory of linear model parameters is very mature, the results are very much. However, the actual model in reality is often not a linear model, but a nonlinear regression model. Using the theory of linear models to deal with nonlinear regression models is just a simple, approximate method. This approximation often brings about many problems and leads to conclusions that are not consistent with the facts . Therefore, it is natural to think that since the actual model is a nonlinear regression model, the actual model should be treated with nonlinear science. Nonlinear science has inspired almost all scientific researchers in the natural sciences, engineering technology and social sciences in the past 30 years, and has posed epoch-making challenges to people. It is due to the role of nonlinearities that have given rise to the thousands of phenomena in nature, the changes in human societies, and the intricate differences in human thinking, and in recent decades, the dissipative structures, lone particles, self-organization, synergisms, super-cycles and micro-cycles, singular attractors and In recent decades, the introduction and development of theories such as dissipative structures, solitary particles, self-organization, synergism, super-circulation and micro-circulation, strange attractor and chaotic dynamics, etc. have made people realize that nonlinearity is the source of all complex problems. Nonlinear science is a new kind of discipline to study complexity phenomena, therefore, to study various natural phenomena and even social phenomena in depth, precisely and practically, it is necessary to study nonlinear problems. In terms of the nature of the model parameters, the major difference between the nonlinear regression model and the linear model lies in the fact that after the usual assumptions of independent, identically distributed, and normal random terms are stipulated, the linear model produces unbiased, normally distributed, and very small variance parameter estimates, but the nonlinear regression model parameter estimates do not have this property, but instead produce biased, unnormal, and biased estimates with more than a very small variance.

Multiple nonlinear regression analysis is a class of regression analysis, characterized by: (1) a dependent variable is jointly influenced by multiple independent variables, and the correlation equation of their joint action needs to be explored. (2) The regression pattern between the dependent variable and multiple independent variables is represented as curves of different shapes on the image. The regression model is expressed in the form shown in Equation (9), and the empirical regression model derived from the analysis of a large amount of data is expressed in the form shown in Equation (10), ($i = 1, 2, 3, \cdots\cdots$). For:

$$y = \beta_0 + \beta f\left(x_{i1}\right) + \beta_2 f\left(x_{i2}\right) + \cdots + \beta_p f\left(x_{ip}\right) + \varepsilon_i \tag{9}$$

$$y = \hat{\beta}_0 + \hat{\beta} f\left(x_{i1}\right) + \hat{\beta}_2 f\left(x_{i2}\right) + \cdots + \hat{\beta}_p f\left(x_{ip}\right) \tag{10}$$

The core of the multiple nonlinear regression method is to establish a good multiple nonlinear regression model, the specific modeling process.

Step 1: Define the research objectives and determine the dependent and independent variables. Regression analysis is mainly to reveal the quantitative relationship between the dependent and independent variables between things. According to the actual problem under study, the dependent and independent variables should be determined in a targeted way through qualitative analysis. In addition, the more dependent variables involved in the regression model is not the better, too many dependent variables will easily lead to poor model accuracy, amplify the accumulation of computational errors, and increase the amount of arithmetic. It usually takes repeated trial calculations to find out the most suitable some variables.

Step 2: Collect and organize relevant data. The establishment of regression model is based on a large amount of actual data as the sample of regression variables. After determining the dependent and independent variables, it is necessary to summarize the data and correspond to the data.

Step 3: Construct the multivariate nonlinear regression theoretical model. Aiming at the researched problem, analyze its internal law and mechanism of action, and make qualitative judgment on the relevant independent variables. Combined with the existing research results, through the establishment of parameters, initially give a certain functional relationship formula.

Step 4: Determine the model parameters. Under normal circumstances, the multiple nonlinear regression theory model contains a certain number of unknown parameters. When the number of samples is large, computerized parameter estimation software such as SPSS, Minitab, SAS, EViews, etc. can be used to obtain the model parameters.

Step 5: Model testing and modification. In order to confirm whether the model established in the previous steps can better describe the relationship between the variables in the problem, the model also needs to be further tested. There are usually two kinds of testing methods: practical testing and statistical testing. If the test found that the established model applicability is poor, then the model needs to be modified.

Step 6: Application of the regression model. After establishing a good multivariate nonlinear regression model, the model can be used to analyze the actual problem.

2.4.2. Explained Variables

Global value chain division of labor position (GVCpo), which indicates the position of China's service industry in the international division of labor, adopts the trade decomposition method as well as the koopman's calculation method to calculate the index of the service industry's global value chain division of labor position in the ADB database from 2014 to 2023, and the specific results of the calculation are shown in subsection 2.3.

2.4.3. Explanatory Variables

The level of digital economy development (DE) according to the core industries of the digital economy will be divided into a number of perspectives to evaluate the level of development of China's digital economy, the higher the composite score, the higher the level of development of the digital economy, the better the quality of the specific results of the calculations, see subsection 2.2.

2.4.4. Control Variables

Global Value Chain Participation (GVCpar) GVC participation also affects the status of the whole value chain to a certain extent, and this indicator represents the level of GVC participation in each industry of the service sector, with specific calculations referred to in subsection 2.3.

Outward foreign direct investment (OFDI) is measured by the proportion of OFDI flows to GDP. Enterprises upgrade China's technological innovation by establishing research centers and attracting advanced research talents and innovative technologies from abroad, which in turn improves their position in the international division of labor.

Labor cost (WAGE) is measured by the proportion of total wages of employees in each industry of the service sector to GDP. Higher wages can attract more high-quality talents to enter the service sector to provide intellectual support for the development of the service sector, enhance productivity and technological innovation, and promote the status of the global value chain.

Infrastructure development (INF) is measured by the proportion of fixed asset investment in each service industry in the total investment of the whole society, and the gradual improvement of infrastructure can further affect the production efficiency, reduce the transaction cost and occupy the high value-added production link, which is conducive to the improvement of the status of the global value chain.

2.4.5. Mathematical Modeling

By drawing on relevant literature, it can be obtained that the digital economy will have a certain impact on the status of the global value chain of the service industry, in order to verify this conclusion and explore the relationship between the level of development of the digital economy and the global value chain of the service industry, this paper selects 11 subsectors of the service industry from 2014 to 2023, and establishes the following nonlinear regression model. Specifically as follows:

$$\begin{aligned} GVC_{pos_{it}} &= \alpha_0 + \alpha_1 \ln DE_{it} + \alpha_2 GVC_{par_{it}} + \alpha_3 OFDI_{it} \\ &+ \alpha_4 WAGE_{it} + \alpha_5 \ln INF_{it} + \mu_{it} \end{aligned} \tag{11}$$

where i denotes the 11 industries of China's service sector, t denotes time, α is the parameter, and μ_{it} denotes the random error term.

3. Analysis of Empirical Studies

3.1. Analysis of the Measurement of the Level of Economic Development

3.1.1. Data Standardization

The initial data for the evaluation indicators of the level of economic development from 2014 to 2023 come from the statistical yearbook, the annual data released by the National Bureau of Statistics, the statistical yearbook of basic units, and the statistical yearbook of the tertiary industry. Among them, the yearly data of individual indicators are missing, and this paper adopts the linear interpolation method to fill in, and the statistical summary of the evaluation indicator data is shown in Table 2. The results show that the evaluation indicator data lies in the range of 10~15.

Table 2. Statistical summary of evaluation index data.

Index	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
X11	11.514	10.253	10.433	12.126	11.268	13.59	10.413	12.411	14.321	10.383
X12	11.706	11.89	10.293	13.629	12.575	13.979	14.561	12.716	14.112	10.991
X13	13.692	12.322	11.399	12.426	12.029	13.466	10.785	10.246	12.514	10.906
X21	13.237	12.184	14.336	12.105	14.525	13.881	11.278	12.769	12.97	14.605
X22	12.992	10.025	10.278	12.431	13.06	14.312	10.458	12.078	12.745	11.56
X23	13.302	14.913	11.591	10.94	12.919	13.768	10.326	14.313	11.605	12.752
X31	11.496	13.211	10.513	10.631	14.365	10.835	14.164	11.363	13.33	13.669
X32	13.893	14.817	12.015	13.667	13.72	12.431	11.706	12.194	11.165	14.454
X33	12.058	11.526	12.532	10.334	10.583	11.875	10.118	13.142	10.791	14.541
X34	13.798	11.202	12.817	13.635	12.699	14.99	12.691	14.301	13.731	14.857
X41	14.267	14.387	14.11	11.557	12.602	10.465	10.039	14.824	13.739	12.038
X42	11.656	13.448	12.757	10.179	12.15	11.947	11.688	11.139	10.486	11.955
X43	14.899	13.415	12.326	13.948	12.454	10.917	13.225	12.176	12.438	11.963
X44	10.27	14.63	14.242	12.712	12.39	13.828	10.052	14.028	14.672	11.701
X45	12.475	11.422	10.344	13.124	12.957	14.968	14.65	10.027	11.148	12.283

Due to the inconsistency of the unit scale of the indicators, they need to be preprocessed to ensure the validity of the research results. The evaluation index data in Table 2 are preprocessed using formula (1), and the preprocessing results are shown in Table 3. After preprocessing, the values of the indicators are kept within the range of 0 to 1.

Table 3. Preprocessing result.

Index	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
X11	0.3100	0.0000	0.0442	0.4604	0.2495	0.8203	0.0393	0.5305	1.0000	0.0320
X12	0.3311	0.3742	0.0000	0.7816	0.5347	0.8636	1.0000	0.5677	0.8948	0.1635
X13	1.0000	0.6024	0.3346	0.6326	0.5174	0.9344	0.1564	0.0000	0.6582	0.1915
X21	0.5888	0.2723	0.9191	0.2486	0.9760	0.7824	0.0000	0.4482	0.5086	1.0000
X22	0.6921	0.0000	0.0590	0.5612	0.7080	1.0000	0.1010	0.4789	0.6345	0.3581
X23	0.6488	1.0000	0.2758	0.1339	0.5653	0.7504	0.0000	0.8692	0.2788	0.5289
X31	0.2552	0.7004	0.0000	0.0306	1.0000	0.0836	0.9478	0.2207	0.7313	0.8193
X32	0.7470	1.0000	0.2327	0.6851	0.6996	0.3467	0.1481	0.2818	0.0000	0.9006
X33	0.4386	0.3183	0.5458	0.0488	0.1051	0.3972	0.0000	0.6837	0.1522	1.0000
X34	0.6853	0.0000	0.4263	0.6423	0.3952	1.0000	0.3931	0.8181	0.6676	0.9649
X41	0.8836	0.9087	0.8508	0.3172	0.5356	0.0890	0.0000	1.0000	0.7732	0.4178
X42	0.4518	1.0000	0.7886	0.0000	0.6029	0.5408	0.4616	0.2937	0.0939	0.5433
X43	1.0000	0.6273	0.3538	0.7612	0.3860	0.0000	0.5796	0.3162	0.3820	0.2627
X44	0.0472	0.9909	0.9069	0.5758	0.5061	0.8173	0.0000	0.8606	1.0000	0.3569
X45	0.4954	0.2823	0.0642	0.6268	0.5930	1.0000	0.9356	0.0000	0.2269	0.4566

3.1.2. Calculation of Weights

On the basis of the initial data preprocessing of the indicators, the weight of the indicators is calculated by applying formula (2), and the results of the weight of the indicators are shown in Table 4.

Table 4. The result of the proportion of the indicator

Index	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
X11	0.0889	0.0000	0.0127	0.1321	0.0716	0.2353	0.0113	0.1522	0.2868	0.0092
X12	0.0601	0.0679	0.0000	0.1418	0.0970	0.1567	0.1814	0.1030	0.1624	0.0297
X13	0.1989	0.1198	0.0666	0.1258	0.1029	0.1859	0.0311	0.0000	0.1309	0.0381
X21	0.1025	0.0474	0.1600	0.0433	0.1699	0.1362	0.0000	0.0780	0.0885	0.1741
X22	0.1507	0.0000	0.0128	0.1222	0.1542	0.2177	0.0220	0.1043	0.1382	0.0780
X23	0.1284	0.1980	0.0546	0.0265	0.1119	0.1486	0.0000	0.1721	0.0552	0.1047
X31	0.0533	0.1463	0.0000	0.0064	0.2088	0.0175	0.1979	0.0461	0.1527	0.1711
X32	0.1482	0.1983	0.0462	0.1359	0.1388	0.0688	0.0294	0.0559	0.0000	0.1786
X33	0.1189	0.0863	0.1479	0.0132	0.0285	0.1077	0.0000	0.1853	0.0412	0.2710
X34	0.1144	0.0000	0.0711	0.1072	0.0659	0.1669	0.0656	0.1365	0.1114	0.1610
X41	0.1530	0.1573	0.1473	0.0549	0.0927	0.0154	0.0000	0.1731	0.1339	0.0723
X42	0.0946	0.2094	0.1651	0.0000	0.1262	0.1132	0.0966	0.0615	0.0197	0.1137
X43	0.2142	0.1344	0.0758	0.1630	0.0827	0.0000	0.1241	0.0677	0.0818	0.0563
X44	0.0078	0.1635	0.1496	0.0950	0.0835	0.1348	0.0000	0.1420	0.1650	0.0589
X45	0.1058	0.0603	0.0137	0.1339	0.1267	0.2136	0.1999	0.0000	0.0485	0.0975

In the known proportion of indicators, it can be substituted into the formula (3) ~ (4) to derive the entropy value of the evaluation indicators, coefficient of variation and weights, and the calculation results are shown in Table 5. After calculation, the weights of the secondary indicators range from 0.0398 to 0.1235, and the corresponding weights of the primary indicators range from 0.1823 to 0.2934.

Table 5. Calculation result

First-level indicator	Weight	Secondary indicators	Entropy value	Coefficient of difference	Weight
X1	0.2365	X11	0.7842	0.2158	0.1235
		X12	0.9071	0.0929	0.0532
		X13	0.8955	0.1045	0.0598
X2	0.1823	X21	0.9111	0.0889	0.0509
		X22	0.8731	0.1269	0.0727
		X23	0.8975	0.1025	0.0587
X3	0.2877	X31	0.8335	0.1665	0.0953
		X32	0.8894	0.1106	0.0633
		X33	0.8440	0.1560	0.0893
		X34	0.9305	0.0695	0.0398
X4	0.2934	X41	0.8978	0.1022	0.0585
		X42	0.9023	0.0977	0.0559
		X43	0.9143	0.0857	0.0491
		X44	0.8949	0.1051	0.0602
		X45	0.8782	0.1218	0.0697

3.1.3. Level of Development of the Digital Economy

The weights of the evaluation indicators derived above are substituted into formulas (5)~(6) to calculate the level of digital economic development from 2014 to 2023, and the results of the level of digital economic development are shown in Table 6, in which IOV and MOV are derived from the statistical yearbook. Based on the data in the table, it can be seen that the level of digital economic development in 2014~2016 showed a downward trend, the digital economy in 2017~2019 got a certain rebound, and then due to the epidemic in 2020 led to a sharp decline in the digital economy, and with the epidemic under control, the level of digital economic development in 2021~2022 showed an upward trend again, and finally the level of digital economic development in 2023 shows a small downward trend.

Table 6. Results of the development level of the digital economy(One trillion yuan).

Year	Q	IOV	MOV	DE
2014	0.1120	40.155	6.008	0.7486
2015	0.1006	44.173	6.319	0.7032
2016	0.0683	46.377	6.794	0.4662

2017	0.0849	46.578	7.326	0.5398
2018	0.1108	50.733	8.856	0.6347
2019	0.1325	55.951	10.121	0.7325
2020	0.0633	57.648	12.222	0.2986
2021	0.1013	63.671	13.333	0.4838
2022	0.1186	70.292	13.363	0.6239
2023	0.1076	73.604	14.085	0.5623
Mean	0.1000	54.9182	9.8427	0.5794

3.2. Analysis of Global Services Value Chain Measurement

3.2.1. Analysis of GVC Status Index Measurement

Under the guidance of formula (7), the GVC status index is calculated to derive the GVC status index from 2014 to 2023, and the results of the GVC status index measurement and analysis are shown in Table 7, where IV_{ir} , FV_{ir} , E_{ir} data in formula (7) are from the statistical yearbook. The results show that from 2014 to 2019 $GVC_{positionir}$ increased from the initial value of 0.0159 to 0.4616, and due to the outbreak in 2020, it caused $GVC_{positionir}$ to decrease in value from 0.4616 to 0.1006, and with the end of the outbreak, $GVC_{positionir}$ increased from 0.1006 to 0.4117.

Table 7. Calculation and analysis results of the GVC status index.

Year	IV_{ir}	FV_{ir}	E_{ir}	$GVC_{positionir}$
2014	1.9425	1.8846	1.7244	0.0159
2015	3.6731	2.9518	1.7723	0.1421
2016	6.0145	3.2128	3.9115	0.3316
2017	7.6656	4.1455	4.0733	0.3565
2018	9.7087	4.4693	4.7385	0.4504
2019	9.9999	4.4963	4.8861	0.4616
2020	3.2688	2.6532	3.1628	0.1006
2021	5.3646	3.0923	5.6857	0.2302
2022	7.6692	3.5702	5.9926	0.3567
2023	8.9553	3.8625	6.1341	0.4117
Mean	6.4262	3.4339	4.2081	0.2857

3.2.2. Analysis of GVC Participation Index Measurements

Substituting IV_{ir} , FV_{ir} , E_{ir} data into Equation (8), the GVC Participation Index can be calculated, and the results of the GVC Participation Index Measurement Analysis are shown in Table 8. Take the GVC participation index in 2014 for example:

$$GVC_{participationir} = \frac{IV_{ir}}{E_{ir}} + \frac{FV_{ir}}{E_{ir}} = \frac{1.9425}{1.7244} + \frac{1.8846}{1.7244} = 2.12194$$

The calculation process of GVC participation index in 2015~2023 is the same and will not repeat the description, which has been completed in matlab software. It can be seen that due to the epidemic in the period of 2020~2022, the GVC participation index decreased to 1.8724, 1.4874, 1.8755, and the GVC participation index of other years are above 2.

Table 8. GVC participates in the index calculation and analysis.

Year	IV_{ir}	FV_{ir}	E_{ir}	$GVC_{participationir}$
2014	1.9425	1.8846	1.7244	2.2194
2015	3.6731	2.9518	1.7723	3.7380
2016	6.0145	3.2128	3.9115	2.3590
2017	7.6656	4.1455	4.0733	2.8996
2018	9.7087	4.4693	4.7385	2.9921
2019	9.9999	4.4963	4.8861	2.9668
2020	3.2688	2.6532	3.1628	1.8724
2021	5.3646	3.0923	5.6857	1.4874
2022	7.6692	3.5702	5.9926	1.8755
2023	8.9553	3.8625	6.1341	2.0896
Mean	6.4262	3.4339	4.2081	2.4500

3.3. Exploratory Analysis of the Relationship between the Two Roles

3.3.1. Descriptive Statistical Analysis

Before the regression analysis, descriptive statistics of the variables are carried out, and based on the previous explanation and data availability, the service industry from 2014-2023 is selected as the panel data, and the data on the level of development of the digital economy (DE), the GVC status index (GVCpo), and the GVC participation index (GVCpar) are derived from the previous measurement and analysis, while the data on outward foreign direct investment (OFDI), labor cost (WAGE), and infrastructure development (INF) are derived from the statistical yearbook. Some variables are logarithmically processed to keep the data smooth, and the results of descriptive statistical analysis are shown in Table 9. The results show that the mean values of Digital Economy Development Level (DE), GVC Position Index (GVCpo), GVC Participation Index (GVCpar), Outward Foreign Direct Investment (OFDI), Labor Costs (WAGE), and Infrastructure Development (INF) are 0.5794, 0.2857, 2.4500, 4.548, 68.198, and 75.103. The size of the data distribution of the variables is demonstrated to provide theoretical support for the following.

Table 9. Descriptive statistical analysis results.

Variable	Mean value	Standard deviation	Minimum value	Maximum value
DE	0.5794	0.1395	0.2986	0.7486
GVCpo	0.2857	0.1552	0.0159	0.4616
GVCpar	2.4500	0.6834	1.4874	3.7380
OFDI	4.548	0.818	1.579	6.579
WAGE	68.198	10.472	25.44	87.93
INF	75.103	13.235	29.455	98.039

3.3.2. Correlation Analysis

Using the Pearson correlation coefficient, the variables in Table 9 were correlated and the results of the correlation analysis are shown in Table 10. From the output results, it can be seen that the digital economy is significantly lower than the 0.05 acceptable level, and the digital economy is significantly and positively correlated with the index of the global value chain status of the service industry. In order to avoid the influence of multicollinearity on the research results, the variance inflation factor (VIF) of the main research variables was calculated, and the maximum VIF value of 6.24, the minimum value of 1.06, and the average VIF value of 2.22 were obtained, all of which were lower than the acceptable 10, and it is considered that there is no serious multicollinearity among the variables in this paper.

Table 10. Results of correlation analysis.

Variable		DE	GVCpo	GVCpar	OFDI	WAGE	INF
DE	Pearson	1	0.728	0.641	0.702	0.407	0.718
	Sig		0.009	0.006	0.004	0.003	0.002
GVCpo	Pearson	0.728	1	0.389	0.432	0.688	0.693
	Sig	0.009		0.008	0.002	0.004	0.002
GVCpar	Pearson	0.641	0.389	1	0.561	0.591	0.692
	Sig	0.006	0.008		0.009	0.005	0.005
OFDI	Pearson	0.702	0.432	0.561	1	0.652	0.359
	Sig	0.004	0.002	0.009		0.001	0.009
WAGE	Pearson	0.407	0.688	0.591	0.652	1	0.656
	Sig	0.003	0.004	0.005	0.001		0.008
INF	Pearson	0.718	0.693	0.692	0.359	0.656	1
	Sig	0.002	0.002	0.005	0.009	0.008	

3.3.3. Analysis of Regression Results

Panel data regression analysis using SPSS software, and further using a multidimensional panel fixed effects model, and respectively, year, country, industry fixed effects regression, Table 11 for reporting the results of the basic data regression, Table 11 column (1) did not add control variables and year, country, industry fixed effects, the regression results show that the level of digital technology and the services industry at the 0.05 level of significance GVC status is positively related, column (2) of the table fixes year country and industry on the basis of column (1), and the level of digital technology is still positive at the 1% significance level; columns (3) and (4) of the table include the addition of the GVC Participation Index (GVCpar), outward foreign direct investment (OFDI), labor cost (WAGE), and infrastructure development (INF). Results without and with fixed effects after control variables. The regression results show that the improvement of the level of digital economy development can significantly promote the upgrading of the position of the global services value chain. Looking at the above regression results, the core explanatory variables of the level of digital economy development and its position in the global services value chain are still significantly positively correlated with each other, which explains to a certain extent the robustness of the regression results, and after adding the fixed effects of the country, the industry, and the year, the level of digital economy development is increased by 1 unit each global service industry value chain status improves by 0.042, indicating that the higher the level of digital economy development, the more advantageous it is in the division of labor in the global value chain, advancing the reengineering of the global service industry value chain under the wave of digitization.

Table 11. Analysis of Regression results.

Model	(1)	(2)	(3)	(4)
DE	0.042*** (0.004)	0.026*** (0.004)	0.041*** (0.004)	0.036*** (0.004)
GVCpar			-0.007*** (0.002)	-0.007*** (0.002)
OFDI			-0.003 (0.002)	-0.003 (0.002)
WAGE			-0.003 (0.002)	-0.003 (0.002)
INF			-0.003 (0.002)	-0.003 (0.002)
Constant term	1.014*** (0.008)	1.015*** (0.008)	1.027*** (0.0324)	1.044*** (0.037)
Control variable	No	No	Yes	Yes
Fixed effect	No	No	No	Yes
R^2	0.038	0.026	0.038	0.028

4. Conclusion

This paper refers to relevant information and literature to construct the evaluation index system of digital economy development level, and calculates the value of digital economy development level with the help of entropy weight method, and sets this value as the core explanatory variable. Based on the trade value-added method, the formula for measuring the global service industry value chain is given, and the measured value is also set as the explanatory variable, and four control variables are set afterward. With the help of nonlinear regression model, the mechanism between digital economy and global service industry value chain is explored. It is concluded that there is a significant positive correlation between the level of development of digital economy and the status index of global services value chain, and when the level of development of digital economy increases by 1 unit, the corresponding status index of global services value chain increases by 0.042 units, which demonstrates the role of the two and promotes the reengineering of the global services value chain under the wave of digitization.

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