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Digital economy development and industrial structure upgrading: Empirical evidence from inter-provincial panel data in China

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Abstract: Based on the panel data of 30 provinces in China from 2011 to 2021, this paper uses a two-way fixed effect model to explore the impact of digital economy development on industrial structure upgrading. It is found that the development of digital economy can promote the upgrading of industrial structure. The impact of the development of the digital economy on industrial structure upgrading is more obvious in the central and western regions. The development of the digital economy can promote t industrial structure upgrading by promoting the improvement of the level of scientific and technological innovation. Finally, the paper argues that it is necessary to promote the integration of digital technology development with traditional industries, provide policy support for the development of the digital economy, encourage the deep integration of scientific and technological innovation and industrial upgrading, and give full play to the comparative advantages of regions.

1. Introduction

With the development of economic globalization, international competition has become increasingly fierce. Countries are seeking to improve economic efficiency and competitiveness through industrial structure upgrading. On the other hand, due to the increasing prominence of environmental issues, sustainable development and green development have become a global consensus. Governments around the world have incorporated green development into their national development strategies to promote the development of industrial structures in a low-carbon, environmentally friendly and sustainable direction.

At the same time, the new generation of scientific and technological revolution and industrial transformation is developing in depth on a global scale, including artificial intelligence, big data, cloud computing, Internet of Things and other technologies has become an important driving force to promote economic development, the application of digital economy technology, promote the digital transformation of all walks of life, optimize the allocation of resources, improve production efficiency, thereby promoting the optimization and upgrading of the industrial structure. In this context, it is of great theoretical and practical significance to study the impact of the development of digital economy on the upgrading of industrial structure.

2. Literature review

As early as the 90s of the 20th century, the concept of digital economy has been mentioned by scholars (Tapscott, 1996)[1], but there is still no clear definition of digital economy. Mesenbourg (2001) argues that the digital economy is equivalent to e-commerce[2], and Quah (2003) extends the scope to all goods and services transactions using the Internet[3]. Liu and Meng (2019) measured the level of digital economy from two perspectives: the basic industry of the digital economy and the integration effect of the digital economy[4]. Chen et al. (2021) constructed digital economy development indicators from six dimensions: the level of digital infrastructure construction, the development level of emerging digital economy industries, and the level of ICT promotion of digital society[5]. Zhao et al. (2020) included the development level of digital inclusive finance into the measurement of the comprehensive development level of the digital economy on the basis of the Internet development level index[6].

Industrial structure upgrading refers to the change in the relative importance of various industrial sectors in an economic system, usually refers to the process of transformation from traditional industries to high value-added, high-tech and high-efficiency industries. Yu et al. (2021) concluded that human capital dividends can promote the process of industrial structure upgrading through empirical studies such as panel threshold regression and dynamic panel GMM model[7]. Some scholars believe that foreign direct investment, industrial policies, and environmental regulations can all drive industrial structure upgrading (Huang & Chen, 2007; Han et al., 2017; Zheng, 2016; Wang & Li, 2024)[8][9][10][11]. Yao et al. (2021) found that the digital economy can positively promote the upgrading of industrial structure, and the intensity of R&D investment plays a mediating role in it[12].

3. Theoretical mechanism analysis and research hypothesis

The upgrading of industrial structure refers to the process of developing the industrial structure of a country or region in the direction of higher technological content, richer added value and stronger innovation ability. On the one hand, the wide application of digital technology can improve the efficiency of production, management and services, reduce the marginal production cost of enterprises, and enhance the competitiveness of enterprises (Jiao & Sun, 2021)[13]. On the other hand, the digital economy, with its innovation and technology-orientation, promotes the rise of emerging industries and the upgrading of traditional industries, and drives the evolution of the industrial structure to higher value-added and higher technology content (Hong et al., 2023) [14], providing new impetus and growth points for the upgrading of the industrial structure.

The level of scientific and technological innovation refers to the degree and level of scientific research, technological development and innovation activities. Some scholars believe that the development of the digital economy can provide innovative incentives for the construction of a modern economy (Jing & Sun, 2019)[15]. Specifically, the digital economy provides an efficient platform for information dissemination and sharing, so that knowledge, technology and experience in the field of science and technology can be disseminated and shared more quickly, which helps to avoid duplication of research and accelerate technology iteration, thereby promoting the acceleration of scientific and technological innovation (Zhang, 2019)[16]. At the same time, the digital economy provides an open platform for innovation, making it easier for businesses to interact and collaborate with consumers (PEE, 2016, Chen, 2018)[17][18]. The improvement of the level of scientific and technological innovation has accelerated the elimination of backward industries, and advanced scientific and technological innovation has also promoted the development of emerging industries, such as artificial intelligence, biotechnology, new energy and other fields. These emerging industries often have high value-added and high-tech content, which can drive the upgrading and transformation of the entire industrial chain and promote the development of traditional industries in the direction of

high technology and high added value (Gao et al., 2017)[19].

Based on the above analysis, the following hypotheses are proposed:

Hypothesis 1. The development of the digital economy can promote the upgrading of the industrial structure.

Hypothesis 2. The development of the digital economy can promote the upgrading of the industrial structure by improving the level of scientific and technological innovation.

4. Methods setting and data sources

4.1. Model setting

In order to empirically test the impact of the development level of the digital economy on the upgrading of industrial structure, the following time and individual two-way fixed effect models are constructed:

$$High_{it} = \alpha_0 + \alpha_1 Index_{it} + \alpha_2 Control_{it} + \lambda_i + \theta_t + \varepsilon_{it} \tag{1}$$

In equation(1), i represents the province, t represents the year, *High* represents the upgrading of the industrial structure, *Index* represents the index of the level of digital economy development, *Control* represents all control variables, λ_i is the individual fixed effect, θ_t is the annual fixed effect, and ε_{it} is the random perturbation term.

4.2. Variable declaration

4.2.1. Dependent variable

The upgrading of industrial structure refers to the process of transforming the industrial structure to an industry with higher technical content, higher added value and stronger innovation ability. Most of the literature measures the upgrading of industrial structure by the ratio of tertiary industry to secondary industry, but this method does not consider the development of the primary industry. In order to measure the upgrading of industrial structure more comprehensively, this paper draws on the practice of Feng et al. (2022)[20] to include the primary industry in the index of upgrading through the following formula:

$$high_{it} = \sum_{j=1}^{3} \frac{Y_{it,j}}{Y_{it}} \cdot j \tag{2}$$

In the formula, *high* represents the level of industrial structure upgrading, i represents the province, j represents the industry, t represents the year, Y_{it} represents the gross regional product, $Y_{it,j}$ represents the added value of the j industry, and the larger the *high* value, the higher the level of industrial structure upgrading.

4.2.2. Explanatory variables

The core explanatory variable of this paper is the index of the level of digital economy development. This paper measure digital inclusive finance from three aspects: coverage breadth, depth of use, and degree of digitalization, and measure the level of digital economy development from four dimensions: infrastructure digitalization, digital application popularity, digital industry development, and digital inclusive finance. The entropy method is used to obtain the weights of each index, as shown in Table 1, and the weights are weighted and summed by the standardized indicators

to obtain the annual digital economy development level index of each province, so as to measure the level of digital economy development in each province.

Table 1: Indicator system of digital economy development level

dimension	index	Metric attributes	weight
Level of digitalization of infrastructure	Number of domain names (10,000)	+	0.08987
	IPv4 URLs (10,000)	+	0.13631
	Number of Internet broadband access ports (10,000)	+	0.06141
	Length of long-distance fiber optic cable per unit area (km/sq km)	+	0.12896
The popularity of digital applications	Mobile phone penetration rate (per 100 people)	+	0.01922
	Number of information-based enterprises	+	0.19420
	Number of websites per 100 businesses	+	0.01089
	The proportion of enterprises with e-commerce transaction activities	+	0.03195
Development of the digital industry	E-commerce Transaction Value (100 million yuan)	+	0.14531
	Software business revenue (10,000 yuan)	+	0.19174
Digital financial inclusion	Digital Finance Coverage Breadth Index	+	0.02738
	Digital finance uses a depth index	+	0.02503
	The degree of digitalization of digital finance	+	0.01861

4.2.3. Control variables

In order to reduce the error caused by the influence of other factors, this paper selects trade openness, foreign direct investment, government intervention, infrastructure construction, fixed asset investment, informatization level and financial development level as control variables. Trade openness (*ope*) is measured as a percentage of GDP in terms of total imports and exports converted into the average exchange rate between the US dollar and the renminbi in the current year. Foreign direct investment (*fdi*) is measured as a percentage of GDP by province; Government intervention (*gov*) is measured as the ratio of regional fiscal expenditure to regional GDP; Infrastructure construction (*inf*) is measured by the per capita length of roads in each province, that is, the ratio of the length of roads in each province to the number of permanent residents at the end of the year. Investment in fixed assets (*invest*) is measured as the ratio of total fixed assets to gross regional product; The level of informatization (*inl*) is measured by the ratio of the total volume of post and telecommunications services to the gross regional product; The level of financial development (*fin*) is measured by the ratio of the balance of deposits and loans of financial institutions to the gross regional product.

4.2.4. Mediator variables

In this paper, the level of scientific and technological innovation (*innov*) is analyzed as a mediating variable. The level of scientific and technological innovation (*innov*) is measured by the proportion of science and technology fiscal expenditure to general fiscal expenditure, which can reflect the support and investment of a country or region in scientific and technological innovation to a certain

extent, so it can be used as an important indicator to measure the level of scientific and technological innovation.

4.3. Data sources and descriptive statistics

Considering the availability of data, the data used in this paper are panel data of 30 provinces, autonomous regions and municipalities in China (excluding Hong Kong, China, Macao, China, Taiwan, China and Tibet) from 2011 to 2021, and the data used are from the National Bureau of Statistics, China Statistical Yearbook, Statistical Yearbooks of various provinces, autonomous regions and municipalities, China Marketization Index Database, Peking University Digital Finance Research Center of Peking University, and the statistical bulletins of national economic and social development of various provinces. The descriptive statistical results for the main variables are shown in Table 2.

Table 2: Descriptive statistics of variables

variable	Sample size	Mean	median	Standard deviation	Min	Max
Upgrading of industrial structure	330	2.397	2.387	0.123	2.132	2.834
The level of development of the digital economy	330	0.138	0.103	0.110	0.0170	0.655
Trade openness	330	0.272	0.145	0.285	0.00800	1.464
Foreign direct investment	330	0.0200	0.0170	0.0180	0	0.121
Government intervention	330	0.276	0.248	0.129	0.107	0.846
Infrastructure development	330	0.0290	0.0280	0.0120	0.00700	0.0680
Investment in fixed assets	330	0.833	0.855	0.288	0.205	1.597
Level of informatization	330	0.0600	0.0360	0.0550	0.0140	0.290
Level of financial development	330	3.395	3.181	1.088	1.678	7.578
Level of scientific and technological innovation	330	10.21	10.30	1.454	6.219	13.68

5. Empirical results and analysis

5.1. Benchmark regression

Table 3 shows the three regression results of the digital economy development level index on the upgrading of industrial structure.

Columns (3) is fixed-effect regression results, and it can be seen that the coefficient of the development of the digital economy on the upgrading of industrial structure is 0.176, and it is significantly positive at the 1% level. This shows that the development of the digital economy can transform the industrial structure to an industry with higher technological content, higher added value and stronger innovation ability by promoting technological innovation, giving birth to emerging

industries, and increasing the added value of products.

Table 3: Baseline regression

	(1)	(2)	(3)
	OLS	RE	FE
Variable	*high*	*high*	*high*
index	0.260***	0.263***	0.176***
	(0.044)	(0.039)	(0.049)
ope	0.058***	0.153***	0.124***
	(0.020)	(0.016)	(0.019)
fdi	-0.122	-0.187*	-0.295***
	(0.203)	(0.110)	(0.111)
gov	-0.196***	0.197***	0.309***
	(0.039)	(0.042)	(0.047)
inf	0.052	1.339***	1.191***
	(0.265)	(0.380)	(0.431)
invest	0.029*	-0.008	0.002
	(0.016)	(0.008)	(0.008)
inl	0.123**	-0.134**	-0.111**
	(0.058)	(0.058)	(0.056)
fin	0.077***	0.028***	0.014**
	(0.005)	(0.005)	(0.006)
Constant	2.105***	2.106***	2.126***
	(0.018)	(0.021)	(0.022)
Sample size	330	330	330
r2	0.823		0.891
		Prob>chi2 = 0.0000	

Note. ***, **, * respectively indicate that the estimated parameters are significant at the significance level of 1%, 5% and 10%, and the standard error is in brackets. The same below.

5.2. Robustness test

Table 4: Robustness test

	(1)	(2)	(3)
		Phase 1	Phase 2
variable	*high*	*index*	*high*
IV		0.066*** (0.019)	
index			0.414**
			(0.207)
L.index	0.209***		
	(0.051)		
fdi	-0.313***	0.189	-0.486***
	(0.106)	(0.181)	(0.137)
gov	0.252***	-0.171**	0.301***
	(0.048)	(0.070)	(0.066)
inf	1.428***	3.139***	2.398***

	(0.407)	(0.461)	(0.769)
invest	0.005	0.040***	0.018
	(0.008)	(0.012)	(0.013)
inl	-0.096*	-0.296***	0.123***
	(0.051)	(0.106)	(0.030)
fin	0.017***	0.039***	0.038***
	(0.006)	(0.007)	(0.009)
Constant	2.128***	0.000	2.125***
	(0.021)	(0.028)	(0.086)
N	300.000	330.000	330.000
r2	0.893	0.722	0.968

5.2.1. Explanatory variables lag by one period

Column (1) in Table 4 shows the regression results of the digital economy development level index after a lag of one period (*L.index*), and the results show that the estimation coefficient of industrial structure upgrading is still significantly positive, which verifies the reliability of the benchmark regression results.

5.2.2. Endogeneity problems

Due to problems such as missing variables, reverse causality, and sample selection bias, there may be endogeneity problems in metrology identification. Therefore, this paper introduces the total amount of telecommunication services per capita in the region as a tool variable (*IV*) for the development of digital economy for the endogeneity test. Regression was performed using the two-stage least squares method. Table 4 shows the two-stage regression results, column (2) shows that the instrumental variables are significantly correlated with the core explanatory variables, and column (3) shows that the coefficients of the core explanatory variables are still significantly positive after the addition of instrumental variables, and the level of digital economy development will still promote the upgrading of industrial structure after eliminating endogeneity.

5.3. Regional heterogeneity analysis

China is a country with a vast territory and uneven development. There are significant differences in economic development, industrial structure and resource endowment between the eastern, central and western regions. The 30 provinces, municipalities and autonomous regions were divided into the eastern region, the central region and the western region, and the samples were grouped and regressed, and the results are shown in Table 5. It can be seen that the development of the digital economy has a positive and significant impact on the upgrading of the industrial structure in the central and western regions, but has no significant impact on the eastern region. The absolute value of the estimation coefficient of digital finance on the industrial structure upgrading in the central region is greater than that in the eastern and western regions, indicating that the development of the digital economy has a more obvious impact on the industrial structure upgrading in the central region.

Table 5: Heterogeneity analysis

	(1)	(2)	(3)
	eastern	Central	Western
variable	*high*	*high*	*high*
index	0.064	1.333***	0.461**
	(0.052)	(0.335)	(0.183)
ope	0.088***	0.394***	-0.027
	(0.018)	(0.126)	(0.060)
fdi	-0.035	-0.012	0.345
	(0.115)	(0.485)	(0.457)
gov	-0.010	0.347*	0.386***
	(0.104)	(0.198)	(0.062)
inf	1.288**	-1.495	2.585***
	(0.512)	(1.529)	(0.775)
invest	-0.024**	-0.017	0.019
	(0.011)	(0.021)	(0.013)
inl	0.099	-0.151	-0.108
	(0.087)	(0.236)	(0.092)
fin	0.023***	0.059**	0.003
	(0.007)	(0.023)	(0.009)
Constant	2.224***	1.995***	2.063***
	(0.040)	(0.064)	(0.032)
N	121.000	88.000	121.000
r2	0.950	0.948	0.887

5.4. Mechanism analysis

5.4.1. Setting of the mediating effect model

The benchmark regression model in the previous paper proves that the improvement of the development level of the digital economy can promote the upgrading of industrial structure, but it is necessary to further study the mechanism of this effect. Based on the above hypotheses and the benchmark fixed-effect model, this paper uses the three-step mediation effect method to test the mediating role of scientific and technological innovation level between the development of digital economy and the upgrading of industrial structure, and the mediating effect model is as follows:

$$Med_{it} = \beta_0 + \beta_1 Index_{it} + \beta_2 Control_{it} + \lambda_i + \theta_i + \varepsilon_{it} \tag{3}$$

$$High_{it} = \gamma_0 + \gamma_1 Index_{it} + \gamma_2 Med_{it} + \gamma_3 Control_{it} + \lambda_i + \theta_i + \varepsilon_{it} \tag{4}$$

5.4.2. Analysis of the mediating effect

The level of scientific and technological innovation (*innov*) is measured by the proportion of science and technology fiscal expenditure to general fiscal expenditure. The regression coefficients in column (1) in Table 6 are significant, indicating that the development of the digital economy provides all-round support for scientific and technological innovation by providing rich data resources, promoting technological innovation, changing innovation models and improving innovation ecology, and significantly promotes the development of scientific and technological

innovation. (2) The regression results of scientific and technological innovation are positive and significant, indicating that scientific and technological innovation may promote the extension of the industrial chain to the high-end and improve the added value and competitiveness of the industry by promoting the emergence of new technologies, new industries and new business forms, thereby promoting the development of the industrial structure in the direction of upgrading.

Table 6: Mechanism analysis

	(1)	(2)
variable	*innov*	*high*
index	0.073***	0.142***
	(0.011)	(0.052)
innov		0.464*
		(0.255)
ope	0.022***	0.114***
	(0.004)	(0.019)
fdi	0.056**	-0.321***
	(0.026)	(0.111)
gov	0.004	0.306***
	(0.011)	(0.047)
inf	0.019	1.182***
	(0.100)	(0.429)
invest	0.005**	0.000
	(0.002)	(0.008)
fin	-0.002	0.015***
	(0.001)	(0.006)
inl	-0.007	-0.108*
	(0.013)	(0.056)
Constant	0.006	2.123***
	(0.005)	(0.022)
N	330.000	330.000
r2	0.434	0.893

6. Conclusions and policy recommendations

In order to verify the impact of the development of the digital economy on industrial structure upgrading, this paper measures the index of the level of digital economy development using China's inter-provincial panel data from 2011 to 2021. The empirical results show that: first, the development of the digital economy has significantly promoted industrial structure upgrading; Second, there is regional heterogeneity in the impact of digital economy on industrial structure upgrading, and the digital economy can significantly promote the upgrading of industrial structure in the central and western regions, and the impact on the central region is greater. Third, the development of the digital economy indirectly affects industrial structure upgrading by improving the level of regional scientific and technological innovation, and the level of scientific and technological innovation has an intermediary role in promoting the upgrading of the industrial structure.

Based on the above conclusions, this paper puts forward the following recommendations:

First, promote the integration of digital technology development with traditional industries. We need to strengthen the construction of digital infrastructure, invest in and optimize digital infrastructure such as high-speed Internet, cloud computing, and big data centers, and ensure the wide

application and efficient operation of digital technologies.

Second, provide policy support for the development of the digital economy. It is necessary to optimize the policy environment for the digital economy, formulate and improve laws, regulations and policy measures related to the digital economy, and provide institutional guarantees for the healthy development of the digital economy.

Third, encourage the deep integration of scientific and technological innovation and industrial upgrading. The government and enterprises should increase investment in scientific and technological innovation, increase the proportion of R&D expenditure in fiscal expenditure, and support the research and development of key common technologies and cutting-edge technologies.

Fourth, we should give full play to the comparative advantages of different regions. For regions with more mature digital economy development, we should focus on promoting the deep integration of the digital economy with high-end manufacturing and modern service industries to enhance the value of the industrial chain. For regions where the development of the digital economy is relatively lagging behind, priority should be given to strengthening the construction of digital infrastructure, cultivating the industrial ecology of the digital economy, and promoting the digital transformation of traditional industries.

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