Research on the Driving Mechanism of Digital Economy on Industrial Upgrading: Empirical analysis based on Provincial Panel Data in China

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Abstract. Digital technologies are driving transformative change, China's economic paradigms are shifting. We calculate the digital economy development index by using the principal component analysis, based on the provincial panel data of China from 2015 to 2020. Then we analyze the impact of digital economy development on the upgrading of industrial structure on the use of fixed effect model and mediating effect model. As a result of the study, the development of digital economy has a significant positive role in promoting the optimization and upgrading of industrial structure, the development of urbanization has a significant partial intermediary effect on the impact of the development of digital economy on the upgrading of industrial structure. We confirmed the necessity of the further development of digital technology. The policymakers need to strengthen the development of regional digital technology, accelerate the construction of regional digital economy, and promote urbanization.

Keywords: Digital Economy; Urbanization; Industrial Upgrading

1 Introduction

In recent years, a new generation of digital technologies, such as big data, cloud computing, artificial intelligence, the internet of things and 5G, has developed rapidly. The world has entered the era of digital economy, which has become an important driving force for global economic development. Developing digital economy is a strategic choice to seize the new opportunities of the new round of scientific and technological revolution and industrial transformation. Digital economy is regarded as a new engine to promote the upgrading of industrial structure, which is conducive to the development of China's economy. Therefore, the study of how digital economy drives industrial upgrading, and its driving mechanism, direction and effect are of great significance for taking measures to improve the contribution of digital economy and formulating scientific and feasible policies to promote industrial upgrading.

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2 Driving Mechanism of Digital Economy on Industrial Upgrading

The driving mechanism of digital economy to industrial transformation and upgrading is mainly realized through industrial digitization and digital industrialization.

Industrial digitalization is the underlying foundation of the digital economy. Traditional industries use AI, big data and other digital technologies in R&D, production, sales, logistics and other links, take informatization as a bridge for market resource allocation, and improve production efficiency. Meanwhile, the digital economy promotes the accelerated integration of different industries, leading to the gradual disappearance of inter-industry barriers, accelerating industrial restructuring, and further promoting the transformation of traditional industries.

Digital industrialization is the core industry of digital economy. Through the application of digital technology and information technology, data, knowledge and information will be transformed into production factors, and new products, services and even industries will be generated. New growth drivers will be fostered and used to promote industrial upgrading.

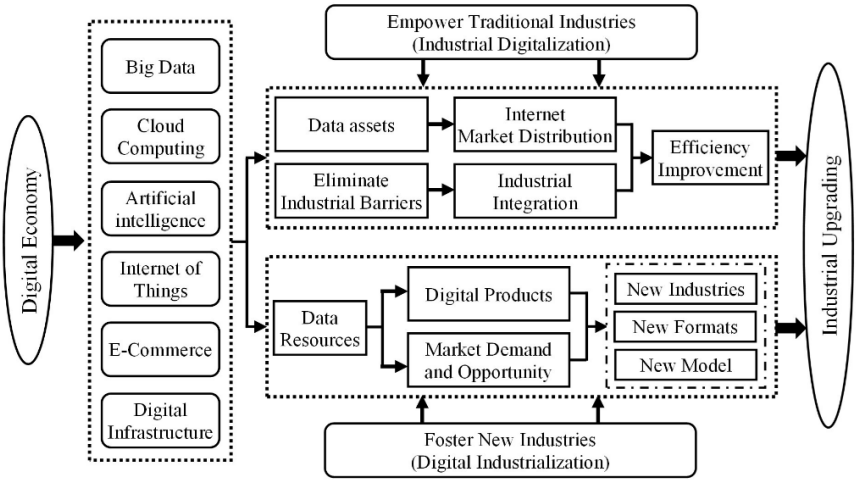

Fig. 1. Driving Mechanism of Digital Economy to Industrial Upgrading [Drawn by the authors]

3 Theoretical Analysis and Research Hypothesis

3.1 Digital Economy Development and Industrial Upgrading

With the vigorous development of digital economy, the influence of digital economy on industrial structure has been gradually taken seriously. Zhang Yuzhe et al. (2018) proposed that the digital economy is the source of economic growth, the driving force of economic transformation and upgrading, and the commanding heights of a new

round of global industrial competition [1]. Li Xiaozhong et al. (2020) used PVAR model and impulse response model to analyze the dynamic interaction between digital economy and the transformation and upgrading of industrial structure in different regions, and found that digital economy and its subsystems have positive promoting effects on the transformation and upgrading of industrial structure in China [2].

The development of digital technology has an important driving force for industrial digitization, the formation of emerging industries and the change of demand, which is conducive to the transformation of China's economic growth model from factor input to innovation driven. New technologies continue to emerge in digital infrastructure and digital industry. Through the application of innovative digital technology, enterprises can achieve digital transformation and obtain economies of scale, which not only improves the technical level and output efficiency of enterprises, but also promotes the high-end development of the entire industry level, and effectively promotes the upgrading of industrial structure. Therefore, we propose hypothesis 1.

Hypothesis 1: Improving the development of digital economy can promote industrial upgrading.

3.2 Development of Digital Economy and Urbanization

In terms of the relationship between digital economy and urbanization, scholars have proposed that digital economy, with its high permeability, scale effect and network effect, accelerates the flow of information and knowledge factors, optimizes resource allocation, promotes the cross-border integrated development of factors, and promotes the process of new urbanization.

Huang Rui et al. (2019) analyzed the effect of information technology on urbanization development and proposed that information technology production industry is conducive to the improvement of the development speed of population and spatial urbanization [3]. Yang Rui et al. (2022) proposed that digital economy accelerates personnel flow, financial integration, infrastructure connectivity, government linkage and ecological civilization construction, and influences the process of new urbanization from five dimensions: population, economy, space, society and ecology [4]. Therefore, we propose hypothesis 2.

Hypothesis 2: Improving the development of digital economy can improve the development of urbanization.

3.3 Urbanization Development and Industrial Upgrading

In the process of urbanization, the number and scale of cities continue to expand, and the structure and function of cities continue to enhance. Non-agricultural industries continue to gather and develop in cities, and labor force and population gradually move to cities. The production of enterprises and the lifestyle of residents continue to change, and the urban market gradually develops and improves, providing necessary conditions for the upgrading of industrial structure.

Ji Chengjun et al. (2019) put forward that informatization has a lasting promoting effect on the upgrading of industrial structure, but the promoting effect of industrial

structure upgrading on informatization is not sustainable. Urbanization has a lasting promoting effect on the upgrading of industrial structure, but the upgrading of industrial structure has a restraining effect on urbanization [5]. Wang Haifeng (2022) proposed that China's new urbanization and the high-quality development of the service industry have significantly promoted the upgrading of the industrial structure, and the driving effect of new urbanization is significantly stronger than the high-quality development of the service industry [6].

Through logical deduction, we believe that digital economy is not only an important driving force in the process of industrial upgrading, but also can improve the level of urbanization development through the impact on resources and factors, thus promoting industrial upgrading. Therefore, we propose hypothesis 3.

Hypothesis 3: Urbanization plays an intermediary role in the process of industrial upgrading promoted by digital economy, that is, the development level of digital economy promotes the development of urbanization, and then promotes the industrial upgrading.

4 Research Design

4.1 Variable Selection

Interpreted Variable

The explained variable is the degree of industrial structure upgrading (IU). The process of industrial structure upgrading is actually a process in which the proportion of tertiary industry is increasing and the proportion of primary industry is decreasing. In order to express this dynamic process, we use the index of Shi Enyi et al. (2018) to describe the process of industrial structure upgrading, and the evaluation index of industrial structure upgrading is represented by IU [7]. In formula 1, Yi represents the proportion of the added value of industry i (i=1-3) in GDP. The smaller IU is, the lower the industrial level is. The larger IU is, the higher the industrial level is.

$$IU_{it} = \sum_{i=1}^{3} iY_{\mathrm{i}} = Y_1 * 1 + Y_2 * 2 + Y_3 * 3 \quad (1)$$

Core Explanatory variables

The core explanatory variable is the level of digital economy development (DE). We select 17 indicators from digital industrialization, industrial digitalization, digital economic infrastructure and digital economic development environment to construct an index evaluation system to evaluate the development level of digital economy (Table 1). Since the data units of different indicators in the index system are not comparable and uniform, in order to avoid the deviation of the evaluation results, data standardization processing is carried out before analyzing the data, and then the principal component analysis method is used to measure, and finally the digital economic development evaluation index is obtained. The larger the index, the better the development of digital economy.

Table 1. Digital Economy Development Evaluation Index System [Authors' computation]

Grade1	Grade2	Grade3
Digital Economy Development Index	Digital Industrialization	Total telecom business volume
		Software business revenue
		Information technology service revenue
		Employees in information transmission, software and information technology service
	Industrial Digitalization	Proportion of enterprises with e-commerce transactions
		Per capita e-commerce sales
		Per capita e-commerce purchase
		Per capita delivery volume
	Digital Economy Infrastructure	Mobile phone penetration rate
		Mobile phone base station density
		Internet broadband access user density
		Internet broadband access port density
		Optical cable line length density
	Digital Economy Development Environment	Per capita local financial expenditure on education
		Per capita local financial expenditure on science and technology
		Employees in Scientific research and technical service in urban unit
		Technology market turnover

Mediator Variable

We choose the level of urbanization development (URB) as the mediator, which is expressed by the proportion of urban population in the total population of the region.

Control Variable

The control variables that may affect regional industrial upgrading include opening to the outside world (OPE), financial development (FIN), regional innovation (RIC), and human capital (EDU). Among them, the opening to the outside world is represented by the proportion of the total volume of regional import and export to the regional GDP; Financial development is expressed by the proportion of the balance of deposits and loans of financial institutions to the regional GDP; Regional innovation is represented by the logarithm of the number of regional patent applications authorized (LnRIC). Human capital is expressed as the proportion of the number of college students to the regional population.

4.2 Data Source

All data are from China Statistical Yearbook, China Statistical Yearbook of Science and Technology and CSMAR database. We selected the provincial panel data of 30 provinces in China (excluding Tibet, Hong Kong, Macao and Taiwan) from 2015 to

2020 for research, based on the principle of data availability, comprehensiveness and comparability. Descriptive results of each variable are shown in Table 2.

Table 2. Descriptive Statistics of Variables [Authors' computation]

Variable	Obs	Mean	Std. Dev.	Min	Max
IU	180	2.426638	0.113555	2.20006	2.834303
DE	180	2.999722	2.182939	0.48	12.94
URB	180	0.6165632	0.1092079	0.4293373	0.8930868
OPE	180	0.2416244	0.2371785	0.007609	1.040305
FIN	180	4.278253	8.077723	1.476168	95.6799
LnRIC	180	10.44453	1.312623	7.104144	13.47263
EDU	180	0.0210767	0.0051013	0.0099653	0.0412545

4.3 Model Setting

Benchmark model

In order to empirically analyze the impact of digital economy on industrial upgrading, that is, to verify the direct transmission mechanism (H1), we construct the following model by referring to the method of Zhou Xia [8].

$$IU_{it} = \alpha_0 + \alpha_1 DE_{it} + \alpha_c Z_{it} + \delta_i + \varepsilon_{it} \quad (2)$$

IU_{it} is the level of industrial upgrading of province i in year t (t=2015, ..., 2020), DE_{it} is the digital economy development level of province i in year t, Z_{it} is a series of control variables, α_0 is a constant term, α_1, α_c (c=2, 3, 4, 5) is the estimated coefficient, δ_i is the individual fixed effect that does not change over time, ε_{it} is a random error term.

Mediation Effect Model

In addition to the direct transmission mechanism, the indirect mechanism of digital economy on industrial upgrading should also be considered, that is, to test whether the urbanization development level proposed in H2 and H3 is a mediating variable. We construct the following mediating effect models.

$$URB_{it} = \beta_0 + \beta_1 DE_{it} + \beta_c Z_{it} + \delta_i + \varepsilon_{it} \quad (3)$$

$$IU_{it} = \gamma_0 + \gamma_1 DE_{it} + \gamma_2 URB_{it} + \gamma_c Z_{it} + \delta_i + \varepsilon_{it} \quad (4)$$

URB_{it} is the urbanization development level of province i in year t, β_0, γ_0 are the constant terms, β_1, γ_1, β_c, γ_c (c=2, 3, 4, 5) are the estimated coefficients.

5 Empirical Analysis

5.1 Regression Result Analysis

Based on the model set in Formula 2-4, firstly, the F-test of the provincial panel data from 2015 to 2020 was conducted by Stata16 software to determine which was better between the mixed regression model and the fixed effects model. The F values in these three tests are 45.15, 91.78 and 63.01 respectively, and the P value of the F-test is 0, indicating that the fixed effect model is better than the mixed regression model. Secondly, we use the Hausman test to judge which is better between the fixed effect model and the random effect model. The P values of these three tests were 0.0251, 0.0003 and 0.0139 respectively, which reflected that the fixed effect model was better than the random effect model. Based on the above analysis, we finally decided to use the fixed effects model to analyze the panel data.

In order to test whether urbanization plays an intermediary role, we verify the impact of digital economy development level on industrial upgrading according to model (1), verifies the impact of digital economy development level on urbanization development level according to model (2), and takes the urbanization development level into the model (3) to verify the intermediary role of this variable in the process of digital economy development level affecting industrial upgrading. The intermediary effect test results are shown in Table 3.

Table 3. Mediation Effect Test Results [Authors' computation]

	Model (1) IU	Model (2) URB	Model (3) IU
DE	0.0174***	0.00891***	0.00930***
	(0.00246)	(0.00140)	(0.00239)
OPE	0.0947	0.108***	-0.00361
	(0.0562)	(0.0318)	(0.0501)
FIN	0.000137	-0.000308**	0.000418*
	(0.000196)	(0.000111)	(0.000173)
LnRIC	-0.00151	0.0176***	-0.0176*
	(0.00879)	(0.00498)	(0.00787)
EDU	1.274	5.245***	-3.512*
	(1.448)	(0.820)	(1.408)
URB			0.913***
			(0.126)
_cons	2.340***	0.271***	2.093***
	(0.0753)	(0.0427)	(0.0731)
N	180	180	180

Note: Standard errors in parentheses. * p<0.05, ** p<0.01, *** p<0.001.

According to model (1) in the intermediary effect test results in Table 3, after adding all control variables, the impact coefficient of the digital economy development level is 0.0174, which shows that there is a significant positive correlation between this

variable and industrial upgrading. According to model (2), the impact coefficient of the development level of digital economy is 0.00891, which shows that this variable has a significant positive role in promoting the development level of urbanization. According to model (3), after joining the urbanization development level, the impact coefficients of digital economy development level and urbanization development level on industrial upgrading are 0.00930 and 0.913, respectively. The coefficient of digital economy development on industrial upgrading is reduced and still significant, and urbanization development level has a significant positive role in promoting industrial upgrading. Therefore, the three conditions of the mediating effect test are satisfied. According to the test results of mediating effect, the development level of urbanization plays a partial mediating role in the relationship between digital economy development and industrial upgrading.

For the control variables, the coefficients in these three models have differences in significance and positive and negative signs, indicating that these variables are all correlated with the development level of digital economy. Among them, the coefficient of the degree of opening to the outside world (OPE) basically indicates that with the continuous progress of regional internationalization, the development level of urbanization will be gradually improved, and the industrial structure will be optimized and upgraded. The coefficient of financial development (FIN) basically shows that financial progress is conducive to industrial upgrading. The coefficient of regional innovation (RIC) shows that this index has a significant role in promoting urbanization development. The coefficient of human capital (EDU) indicates that the improvement of education level is conducive to promote the development of urbanization and industrial upgrading.

5.2 Robustness Test

In the robustness test, we select mobile phone penetration rate (MPP) and Internet broadband access user density (IBA) as two explanatory variables to represent the level of digital economy development. After performing F-test and Hausmann test on panel data, it still shows that fixed effects model should be used for analysis. The robustness test results are shown in Table 4.

Table 4. Robustness Test Results [Authors' computation]

	Model 1 IU	Model 2 URB	Model 3 IU	Model 1 IU	Model 2 URB	Model 3 IU
MPP	0.002***	0.001***	0.001**			
	(0.0002)	(0.0001)	(0.0002)			
IBA				0.406***	0.268***	0.197**
				(0.0463)	(0.0225)	(0.0605)
OPE	-0.0468	0.033	-0.077	0.0126	0.071**	-0.042
	(0.0540)	(0.0291)	(0.0474)	(0.0506)	(0.0246)	(0.0483)
FIN	0.000122	-0.0003**	0.0004*	0.0001	-0.0003**	0.0003
	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.00009)	(0.0002)
LnRIC	0.007	0.020***	-0.011	-0.0131	0.005	-0.017*

	(0.0082)	(0.0044)	(0.0077)	(0.0087)	(0.0042)	(0.0081)
EDU	1.055	4.943***	-3.474*	-1.449	3.132***	-3.885**
	(1.457)	(0.785)	(1.435)	(1.438)	(0.699)	(1.425)
URB			0.916***			0.778***
			(0.135)			(0.159)
_cons	2.181***	0.203***	1.995***	2.484***	0.414***	2.162***
	(0.0645)	(0.0347)	(0.0626)	(0.0775)	(0.0377)	(0.0974)
N	180	180	180	180	180	180

Note: Standard errors in parentheses. * p<0.05, ** p<0.01, *** p<0.001.

The results of robustness test show that both MPP and IBA variables have significant promoting effects on industrial upgrading and urbanization development, and both verify the mediating role of urbanization development level in the process of industrial upgrading influenced by the development level of digital economy.

6 Conclusion and Policy Implications

Under the development strategy of Digital China, strengthening the deep integration of digital economy and real economy and accelerating the pace of urbanization will be an important driving force for promoting high-quality economic development. Using panel data of 30 provinces in China from 2015 to 2020, we tested the logical relationship among the development level of digital economy, urbanization development and industrial upgrading. The empirical results show that digital economy has a significant direct driving effect on urbanization and industrial upgrading. The higher the level of digital economy development, the higher the level of urbanization development. Improving the development level of digital economy can effectively promote the development of urbanization, thereby promoting industrial upgrading.

The conclusion of this paper also has reference significance for the development of China's regional digital economy and urbanization development policy. (1) As the development of China's digital economy is still in initial stage, accelerating the construction of digital economy to promote urbanization development is still the only way for China to achieve industrial upgrading at the stage of economic development turning to high-quality development. (2) In order to make urbanization better facilitate industrial upgrading, the provincial governments should strengthen the construction of digital economy, steadily promote urbanization development, and take it as an important driving force to maintain sustainable and healthy economic development.

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