

The Impact of the Digital Economy on Industrial Structure Upgrading from the Perspective of Regional Heterogeneity: Evidence from China's Provinces

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Abstract: The digital economy serves as a crucial engine driving the upgrading of industrial structure and the high-quality development of the economy. Based on the panel data of 31 provinces in China from 2011 to 2023, this paper constructs individual fixed effect models and mediating effect models to systematically examine the impact mechanism of the digital economy on the upgrading of industrial structure. The empirical results show: First, the digital economy can significantly promote the upgrading of industrial structure, and the driving effect exhibits regional heterogeneity with the central region > western region > eastern region. Second, the digital economy can indirectly promote the upgrading of industrial structure by enhancing human capital, and the mediating effect of human capital also shows regional heterogeneity. Specifically, the central region has a complete mediating effect, the western region has a partial mediating effect, and the eastern region has no mediating effect. Therefore, this paper proposes that each region should implement differentiated digital economic development strategies and strengthen talent cultivation and allocation, and improve the regional coordinated development mechanism to achieve the coordinated upgrading of regional industrial structure through the empowerment of the digital economy, and contribute to the high-quality development of the economy.

Keywords: Digital economy, Industrial structure upgrading, Human capital, Regional heterogeneity.

1. Introduction

The report of the 20th National Congress of the Communist Party of China clearly states, "Accelerate the development of the digital economy and promote the deep integration of the digital economy and the real economy." [1] With the rapid development of 5G, artificial intelligence, etc., the multiplier effect of data elements has been continuously unleashed, providing new impetus for traditional industries to improve efficiency and quality. In 2024, the added value of China's core digital economy industries accounted for more than 10% of the GDP, [2] and the scale of the digital economy remained the second largest in the world. [3] As a new engine driving economic high-quality development, the digital economy takes data as its core production factor [3], featuring high innovation, strong penetration, and wide coverage, providing new impetus and paths for the evolution of the industrial structure towards higher levels, better quality, and more reasonable layout. Developing the digital economy is a strategic choice to seize the new opportunities of the new round of technological revolution and industrial transformation [4].

There are significant differences among various regions in China in terms of economic total volume, resource endowment, technological innovation capabilities, and policy environment. [5] For example, the economic total volume of the eastern region is much larger than that of the central and western regions. [6] The eastern region has abundant high-quality talents, resulting in obvious regional incoordination in the development of the digital economy, and thus making the impact mechanism of the digital economy on industrial structure upgrading show differences [7].

Therefore, from the perspective of regional heterogeneity, this paper clarifies the different impacts of digital economies

in different regions on industrial structure upgrading and the mechanisms behind them, [8] so as to activate the greatest advantages of regional digital economy and promote industrial structure upgrading and high-quality economic development [9].

2. Literature Review

Industrial structure upgrading is an important indicator of economic high-quality development. [10] As the core driving force of economic growth in the new era, the interaction between the digital economy and industrial structure upgrading has become the focus of academic research. Regarding the research on the impact of the digital economy on industrial structure upgrading, Guo Meichen et al. (2019) believe that the development of digital industrialization has a relatively obvious direct driving effect on the upgrading of China's industrial structure [11]; Liu Yang et al. (2021) found that the digital economy has a promoting effect on both the upgrading of industrial structure and the rationalization of industrial structure, and the impact of the digital economy on the industrial structure has a non-linear characteristic. [12] Regarding the research on the influencing mechanism, Feng Suling et al. (2022) pointed out that digital industrialization can give rise to new industries, expand the boundaries of industries, and through technological innovation and industrial integration, [13] drive traditional industries to transform towards high-end and intelligentization; Wang Xiaowen et al. (2023) emphasized that the digital economy promotes green technological innovation and provides new impetus for industrial structure upgrading. Regarding regional research, Chen Bing et al. (2021) empirically proved that the digital economy has regional heterogeneity in its impact on China's industrial structure upgrading; Hou Shangfa et al. (2025) found that the impact of the digital

economy on industrial structure upgrading has a Matthew Effect [14].

In conclusion, existing studies have generally confirmed the positive effect of the digital economy on industrial structure upgrading and initially revealed the existence of regional differences, laying a solid theoretical foundation and logical starting point for this paper. [15] However, there are certain limitations: relatively few studies on the regional heterogeneity of the influencing mechanism. [16] Based on this, this paper starts from the perspective of regional heterogeneity, systematically examines the influencing mechanism of the digital economy on industrial structure upgrading, and deeply analyzes the differences in the impact paths of different regions, providing theoretical basis and empirical support for differentiated digital economic development policies [17].

3. Theoretical Analysis

3.1. Direct Impact Mechanism

As the core elements of the digital economy, the flow, sharing, transaction and openness of data elements can break down information silos, realize cross-industry and cross-field integration of data, and stimulate new industries, new formats and new models, that is, digital industrialization. This not only expands the boundaries of the industry, but also changes the competitive pattern and organizational form of traditional industries. New formats spawned by digital industrialization often have higher efficiency and lower marginal costs, and can expand rapidly in market competition, thereby accelerating the process of upgrading the industrial structure. At the same time, the widespread application of digital technology has also given birth to changes in production models such as intelligent manufacturing and industrial Internet, promoting enterprises to leap from "traditional manufacturing" to "intelligent manufacturing", that is, industrial digitalization. This not only significantly improves the efficiency of traditional industries, but also breaks down the information barriers between all links of the traditional industrial chain, optimizes the allocation of factors, and promotes the coordination and integration between industries, so as to achieve structural upgrading within the industry.

3.2. Indirect Impact Mechanism

In the process of integrating with the real economy, the digital economy also promotes the upgrading of industrial structures by directly influencing the use and allocation of resource elements such as human capital. In terms of human capital, firstly, the widespread application of digital technology has placed higher demands on the digital literacy and skill levels of workers, which in turn drives the labor market to improve its overall quality. Secondly, digital technology has significantly lowered the barriers and costs to acquiring knowledge; digital learning platforms have broken down geographical and resource limitations, enabling residents in less developed areas to access high-quality educational resources, thereby promoting a more equal distribution of educational resources and contributing to an overall improvement in the level of human capital nationwide. Highly skilled labor is a key driver of technological research and development as well as innovative applications. The scale and quality of this skilled workforce determine a sector's ability to absorb and innovate technology, thus propelling industrial structures towards higher-end levels. Additionally,

the accumulation of human capital fosters a closer integration of capital and labor in the service industry and productive services sectors, enhancing the added value and technological content of these industries. This acceleration in the development of the service sector contributes to an increase in its share of the national economy and promotes a more advanced industrial structure.

3.3. The Impact of the Digital Economy on the Industrial Structure Shows Regional Differences.

There are significant differences in digital infrastructure, industrial base, human capital stock, and policy environment in the eastern, central and western regions of China, which may lead to regional heterogeneity in the impact of the digital economy on industrial structure upgrading. The digital economy in the eastern region has developed earlier, with perfect infrastructure and a high degree of talent concentration, but the industrial structure is relatively mature, and the role of the digital economy in promoting industrial structure upgrading may be relatively small. The digital foundation in the central and western regions is relatively weak, and there is a lot of room for industrial structure upgrading.

4. Research Design

4.1. Measurement Model Construction

To examine the direct impact of the digital economy on industrial structure upgrading, the following model has been constructed:

$$upg_{it} = \alpha_0 + \alpha_1 dig_{it} + \alpha_m X_{it} + \varepsilon_{it} \quad (1)$$

In Equation (1), upg_{it} represents the industrial structure upgrading index of province i during period t , dig_{it} represents the digital economy development index of province i during period t , X_{it} indicates the level of control variables for province i during period t , ε_{it} is the random disturbance term, α_0 represents the intercept term, and α_1 represents the coefficient of the digital economy variable, reflecting its impact on industrial structure upgrading.

To examine the indirect impact mechanism of the digital economy on industrial structure, intermediate variables (med) are introduced for analysis. Based on Wen Zhonglin's analysis of mediating effects, this paper constructs a mediation effect model using Equation (1), along with Equations (2) and (3), through the stepwise regression method. The specific representation is as follows:

$$med_{it} = \beta_0 + \beta_1 dig_{it} + \beta_m X_{it} + \varepsilon_{it} \quad (2)$$

$$upg_{it} = \alpha_0 + \alpha_1 dig_{it} + \alpha_2 med_{it} + \alpha_m X_{it} + \varepsilon_{it} \quad (3)$$

4.2. Variable Measurement

Explained variables: The explanation variable in this paper is industrial structure upgrading, and the industrial structure upgrading coefficient is selected to illustrate the industrial structure upgrading level (UPG) of each province based on the calculation methods of Xu Min, Jiang Yong and other scholars. The calculation method is $\sum_{i=1}^3 q_i * i$, where q_i is the proportion of the output value of the i th industry. The higher the value, the higher the degree of industrial structure upgrading.

Explanatory variables: The explanatory variable in this

paper is the level of digital economy development, and this paper refers to the research of Zhao Tao and other scholars to construct an evaluation index system for the level of digital economy development, as shown in Table 1. The

comprehensive development index of the digital economy (DIG) is calculated by the entropy method, and the higher the value of the index, the higher the level of digital economy development.

Table 1. Indicators for the Construction of Digital Economy Development

| Primary Indicator | Secondary Indicator | Tertiary Indicator | Attribute |
|-------------------------------------------------|----------------------------------------------|-------------------------------------------------------------------------------------------|-----------|
| Digital Economy Comprehensive Development Index | Internet penetration rate | Internet users per 100 people | Positive |
| | Employees in the digital-related industries | Proportion of employees in urban information transmission, computer services and software | Positive |
| | Output of Internet-related industries | Per capita total telecommunications volume | Positive |
| | Number of mobile phone users | The number of mobile phone users per hundred people | Positive |
| | The development of digital inclusive finance | Peking University Digital Inclusive Finance Index | Positive |

Mediating variables and control variables: Based on the research purpose and referring to the studies of scholars such as Cui Shilin and Song Hongqiao, the following mechanism variables and control variables were selected. Human capital (hum) is measured by the number of students enrolled in higher education per hundred people; social consumption level (soc) is measured by the proportion of retail sales of consumer goods in the regional GDP; foreign trade level (tra) is measured by the proportion of import and export total volume in the regional GDP; R&D intensity (rd) is measured by the R&D expenditure of large-scale industrial enterprises as a proportion of the regional GDP. Among them, human capital is the mediating variable.

4.3. Data Source

Considering the availability of data, this paper selects 31 provinces in China (excluding Hong Kong, Macao and Taiwan) from 2011 to 2023 as the research objects, and the data are mainly derived from the China Economic Database, EPS National Statistics, China Statistical Yearbook, and the Digital Finance Research Center of Peking University.

5. Analysis of Empirical Results

5.1. Descriptive Statistical Analysis

Descriptive statistical analysis was conducted on the variables, and the results are shown in Table 2. The standard deviation of the industrial structure upgrading level is 0.127, indicating that there is little difference in the level among different provinces and years; the average level of digital economy development is relatively low, and the maximum value is much higher than the average value, indicating that there are significant differences in the development of digital economy among different regions and years. Among the control variables, the social consumption level is relatively stable, while the foreign trade level shows severe imbalance among different regions and years, which may be influenced by geographical location and opening-up policies; the degree of R&D investment is overall low. The standard deviation of human capital is the largest, indicating that the level of human capital varies significantly among different regions and years, presenting a clear stratification phenomenon.

Table 2. Descriptive Statistics of Variables

| variable symbol | Variable name | sample size | average value | standard deviation | minimum value | maximum value |
|-----------------|--------------------------------------|-------------|---------------|--------------------|---------------|---------------|
| upg | Upgrading of industrial structure | 403 | 2.390 | 0.127 | 2.166 | 2.844 |
| dig | Level of digital economy development | 403 | 0.254 | 0.140 | 0.109 | 0.914 |
| soc | Social consumption level | 403 | 0.375 | 0.076 | 0.184 | 0.538 |
| tra | Level of foreign trade | 403 | 0.259 | 0.280 | 0.008 | 1.548 |
| rd | Intensity of R&D investment | 403 | 0.011 | 0.006 | 0.000 | 0.026 |
| hum | Human capital | 403 | 2.809 | 0.907 | 1.082 | 5.839 |

5.2. Empirical Analysis Results

First, an analysis is conducted at the national level to explore the impact of the digital economy on the upgrading of the industrial structure, as well as the mediating effect of human capital. Table 3 presents the regression results of the individual fixed effect model. According to Equations (1) - (3), M1 verifies the impact of the digital economy on the upgrading of the industrial structure, M2 verifies the impact of the digital economy on human capital, and M3 verifies the mediating role of human capital in the process of the digital economy influencing the upgrading of the industrial structure.

The results of M1 indicate that the coefficient of dig on upg is positive and significant at the 1% level, suggesting that the level of digital economic development has a positive promoting effect on the overall industrial structure upgrading

of the country; the results of M2 show that the coefficient of dig on hum is positive and significantly positive at the 1% level, indicating that the digital economy helps to enhance the level of human capital; the results of M3 show that after adding the mediating variable hum, the impact coefficient of the digital economy on the industrial structure is still significantly positive, but the coefficient has decreased. At the same time, human capital has a significant positive impact on the upgrading of the industrial structure, which indicates that human capital plays a partial mediating role in the process of the digital economy influencing the upgrading of the industrial structure, that is, the digital economy not only directly promotes the upgrading of the industrial structure, but also indirectly promotes it by improving human capital. Moreover, the results of Table 3 show that the level of foreign trade has a negative impact on the upgrading of the industrial

structure, and the social consumption level and the intensity of research and development investment can both have a positive impact on the upgrading of the industrial structure, which is basically consistent with the results of many previous studies.

Table 3. Results of Mediation Effect Test

| Variable | M1 | M2 | M3 |
|---------------------|-----------------------|------------------------|-----------------------|
| | upg | hum | upg |
| dig | 0.372*** (5.109) | 2.797*** (5.267) | 0.178*** (2.724) |
| hum | | | 0.070*** (11.272) |
| soc | 0.425*** (6.184) | -1.386*** (-2.765) | 0.521*** (8.700) |
| tra | -0.189*** (-5.798) | 0.337 (1.417) | -0.213*** (-7.530) |
| rd | 16.257*** (10.542) | 177.391*** (15.769) | 3.926** (2.279) |
| constant | 2.014*** (59.829) | 0.663*** (2.700) | 1.968*** (67.075) |
| N | 403 | 403 | 403 |
| adj. R ² | 0.339 | 0.384 | 0.508 |

Note: The numbers in parentheses represent the standard error; ***, **, and * indicate significance levels of 1%, 5%, and 10% respectively.

Table 4. Test Results of the Mediating Effect by Region for the Sample

| Variable | Eastern | | | Central | | | West | | |
|---------------------|----------------------|---------------------|----------------------|----------------------|---------------------|----------------------|----------------------|---------------------|----------------------|
| | upg | hum | upg | upg | hum | upg | upg | hum | upg |
| | M1a | M2a | M3a | M1b | M2b | M3b | M1c | M2c | M3c |
| dig | 0.226* (1.796) | 0.810 (0.931) | 0.147 (1.568) | 0.506** (2.402) | 6.368*** (3.801) | 0.296 (1.344) | 0.303*** (3.002) | 1.892*** (2.696) | 0.160* (1.813) |
| hum | | | 0.097*** (10.220) | | | 0.033** (2.601) | | | 0.075*** (7.259) |
| constant | 2.274*** (29.842) | 1.614*** (3.059) | 2.118*** (36.070) | 1.870*** (31.919) | -0.221 (-0.475) | 1.877*** (32.992) | 2.021*** (41.100) | 1.318*** (3.856) | 1.922*** (43.477) |
| control variables | YES | YES | YES | YES | YES | YES | YES | YES | YES |
| N | 143 | 143 | 143 | 104 | 104 | 104 | 156 | 156 | 156 |
| adj. R ² | 0.242 | 0.191 | 0.581 | 0.589 | 0.609 | 0.613 | 0.262 | 0.367 | 0.461 |

Note: The numbers in parentheses represent the standard error; ***, **, and * indicate significance levels of 1%, 5%, and 10% respectively.

In the eastern region, the results of M1a and M2a indicate that the digital economy can positively promote the upgrading of the industrial structure in the eastern region, and the impact of the digital economy on human capital is not significant. It is preliminarily judged that there is no mediating effect of human capital in the eastern region. The further M3a results show that the direct effect of the digital economy on the industrial structure upgrading becomes insignificant after the inclusion of human capital, indicating that the total effect mainly comes from other paths. The Sobel test results also confirm this, with a z value of 0.927 and a corresponding p value of 0.354, indicating that the indirect effect is not significant. This result indicates that human capital did not play a mediating role in the process of the digital economy influencing the industrial structure upgrading in the eastern region. The reason is that the human capital endowment in the

5.3. Regional Heterogeneity Analysis

According to the research objectives, direct and mediating effects were examined by region to explore the regional heterogeneity of the impact of digital economic development on industrial structure upgrading, as well as the regional differences in the mediating effect of human capital. The specific results are shown in Table 4. According to Equations (1)-(3), M1a, M2a, M3a are individual fixed effect regression models for the eastern region, M1b, M2b, M3b are individual fixed effect models for the central region, and M1c, M2c, M3c are individual fixed effect regression models for the western region.

eastern region is already at a relatively high level, and the digital economy's promotion of industrial structure upgrading mainly manifests as a direct technological empowerment effect rather than an indirect transmission through the improvement of human capital levels.

In the central region, the results of M1b and M2b indicate that the digital economy can promote industrial structure upgrading at the 5% significance level, and the impact of the digital economy on human capital is positive at the 1% significance level. The M3b results show that after including human capital, the impact coefficient of the digital economy on industrial structure upgrading is not significant and the value decreases, while the impact of human capital on industrial structure upgrading is significant at the 5% level. This indicates that human capital has played a complete mediating role in the digital economy's influence on the industrial structure upgrading in the central region. The central region is currently in a critical stage where digital economy drives the accumulation of human capital and then

leads to industrial upgrading.

In the western region, the results of M1c and M2c indicate that the digital economy promotes industrial structure upgrading at the 1% significance level, and the digital economy also enhances regional human capital at the 1% significance level. The M3c results show that after including human capital, the direct effect coefficient of the digital economy decreases and becomes significant at the 10% level, while human capital is significant at the 1% significance level. This indicates that human capital has played a partial mediating role in the digital economy's influence on the industrial structure upgrading in the western region. The promotion of industrial upgrading by the digital economy is the result of both direct empowerment and indirect transmission through human capital.

Compared with M1a, M1b, and M1c, it can be observed that the digital economy can promote the upgrading of the industrial structure and there is a significant regional heterogeneity, presenting the pattern of the central region > the western region > the eastern region. The mediating effect of human capital also shows a distribution feature of significant complete mediation in the central region, significant partial mediation in the western region, and insignificant in the eastern region. This also indicates that if the digital economy is developed reasonably and human capital is enhanced, it will not only help promote the upgrading of the industrial structure, but also effectively narrow the gap between backward regions and developed regions.

6. Conclusions and Policy Recommendations

6.1. Conclusion

Based on the panel data of 31 provinces in China from 2011 to 2023, this paper constructs an individual fixed effect model and an intermediary effect model, and empirically tests the influence mechanism of the digital economy on industrial structure upgrading. The results show that, firstly, the digital economy has a significant positive role in promoting industrial structure upgrading. Secondly, from the national level, human capital plays a significant part of the mediating role in the process of affecting the industrial structure upgrading of the digital economy, which verifies the theoretical transmission mechanism of this paper. Finally, there is significant regional heterogeneity in the impact of digital economy on industrial structure upgrading and the mediating effect of human capital. The total effect of the digital economy on industrial structure upgrading shows the characteristics of "central > western > east". The mediating effect of human capital also shows the distribution characteristics of complete mediation in the central region, partial mediation in the west, and no mediation in the east.

6.2. Policy Recommendations

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

Implement a differentiated digital economy development strategy and fully release regional comparative advantages. The eastern region should rely on the advantages of the digital industry, focus on the deep integration of digital technology with high-end manufacturing and modern service industries, and enhance the marginal contribution of the digital economy to industrial upgrading; The central region should accelerate

the construction of digital infrastructure, undertake the transfer of digital industries in the east, and give full play to the strong role of the digital economy in industrial upgrading. The western region should give priority to making up for the shortcomings of digital infrastructure, expand the coverage of the digital economy, and use policy dividends such as "East Data and West Computing" to promote the coordinated development of the digital economy and local industrial upgrading.

Strengthen talent cultivation and allocation. The eastern region should focus on optimizing the structure of high-skilled talents, improving the digital talent introduction and training mechanism, and promoting the improvement of human capital from "quantity" to "quality"; The central region should strengthen vocational education and digital skills training, expand the support of higher education for the digital field, and strengthen the accumulation effect of the digital economy on human capital, so as to amplify the complete mediating effect of human capital. The western region will increase investment in educational resources, promote digital learning platforms, narrow the regional talent gap, and open up the transmission path of "digital economy, human capital, and industrial upgrading".

Improve the regional coordination and factor support system. Establish a digital economy cooperation mechanism in the east, central and western regions, encourage the east to export digital technology, talents and management experience to the central and western regions, and promote the gradient transfer of the digital industry; At the same time, it is necessary to break down the barriers to the flow of regional factors, promote the rational allocation of data, talents and technology across regions, realize the sharing of digital economy dividends and the coordinated upgrading of industrial structure, and promote the high-quality development of the national economy; Finally, it is necessary to improve the market-oriented allocation rules of data elements, strengthen the protection of intellectual property rights, lower the market entry threshold for new forms of the digital economy, and provide a solid institutional guarantee for industrial upgrading. Through multiple measures, we will narrow the gap between regions and achieve coordinated and high-quality development of the digital economy and industrial structure upgrading.

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