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Digital Economy Enabling Industrial Structure Upgrading: The Mediating Role of Human Capital and Regional Heterogeneity

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Abstract: As a key driver of high-quality economic development in the new era, the mechanism through which the digital economy influences industrial structure upgrading warrants in-depth investigation. Based on panel data from 31 provinces, autonomous regions, and municipalities directly under the central government in China from 2011 to 2021, this study employs a two-way fixed effects model to systematically examine the impact of the digital economy on the advancement and rationalization of industrial structure, with a particular focus on the mediating role of human capital and regional heterogeneity. The main findings are as follows: (1) The development of the digital economy significantly promotes both the advancement and rationalization of industrial structure. This conclusion remains robust after a series of robustness checks, including variable substitution. (2) Human capital accumulation serves as an important transmission channel through which the digital economy drives industrial structure upgrading, exhibiting a significant partial mediating effect. Specifically, the digital economy indirectly facilitates industrial structure optimization by enhancing the level of human capital. (3) There is notable regional heterogeneity in the impact of the digital economy on industrial structure upgrading. Compared with the eastern region, the digital economy exerts a more pronounced positive effect on industrial structure upgrading in the central and western regions, suggesting that these regions possess greater potential for industrial structure optimization through digital empowerment. This study provides novel empirical evidence for understanding the intrinsic relationship between the digital economy and industrial structure upgrading, and offers policy insights for tailoring digital economy development strategies to local conditions to accelerate industrial structure optimization and upgrading.

Keywords: Digital economy; Industrial structure upgrading; Human capital; Mediating effect; Regional heterogeneity

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1. Introduction

Leveraging its strong penetrative capacity and advanced digital technologies, the digital economy has rapidly emerged as a significant driver of national economic development. The report of the 20th National Congress of

the Communist Party of China stated that "while accelerating the development of the digital economy, it is necessary to coordinate industrial restructuring with digital development" [1]. According to the *China Digital Economy Development Report (2024)*, China's digital economy accounted for 42.8% of GDP in 2023, an increase of 1.3 percentage points from the previous year, and its contribution to GDP growth reached 66.45%, effectively supporting steady economic expansion. With the further implementation of the 14th Five-Year Plan for Digital Economy Development, the scale of China's digital economy has steadily increased. In 2023, the digital economy's share of GDP reached 42.8%, playing an increasingly important role in promoting high-quality economic development.

As an emerging economic paradigm, the digital economy is characterized by the use of digital knowledge and information as key factors of production, digital technologies as the core driving force, and modern information networks as important carriers. It aims to deeply integrate digital technologies with the real economy, continuously enhancing digitalization, networking, and intelligence, thereby reshaping the direction of economic growth and generating new management strategies. The digital economy primarily consists of the following key components: (1) Digital industrialization, which mainly involves the information and communication industry, including electronic information manufacturing, telecommunications services, software and information technology services, and the Internet industry; and (2) Industrial digitalization, which refers to the integration of digital technologies into traditional industries to promote industrial progress and transformation through technological integration. This encompasses emerging sectors such as industrial Internet, intelligent manufacturing, the Internet of Vehicles, and platform economies. Through digital empowerment, industrial digitalization helps traditional industries increase output and efficiency while creating new industrial forms, models, and business formats.

With data resources as key production factors and modern information networks as primary carriers, the digital economy drives the continuous evolution of economic forms through the integrated application of information and communication technologies and the digital transformation of total factor inputs. This new economic form not only alters traditional production methods and business models but also fosters the emergence and development of emerging industries, providing strong impetus for industrial structure upgrading [2]. Furthermore, the digital economy optimizes resource allocation within industries, thereby effectively adjusting industrial structures. In the context of the new era, the sound development of emerging industries is a crucial factor in enhancing national comprehensive competitiveness. It breaks the limitations of traditional industrial structures and promotes the advancement and rationalization of industrial structures, which in turn serves as an important driving force for high-quality economic development [3]. Therefore, analyzing the impact of the digital economy on industrial structure is of great significance.

This study systematically examines the mechanism through which the digital economy promotes industrial structure upgrading. By analyzing both the advancement and rationalization of industrial structure, it reveals the internal logic of how the digital economy enables industrial structure optimization, thereby enriching the theoretical research at the intersection of digital economy and industrial economics. Unlike existing studies that primarily focus on the direct effects of the digital economy on economic growth and total factor productivity, this study introduces human capital as a mediating variable and identifies the transmission path of "digital economy → human capital accumulation → industrial structure upgrading," deepening the understanding of the indirect impact mechanisms of the digital economy. Furthermore, from a regional heterogeneity perspective, this study compares the differential effects of the digital economy in the eastern, central, and western regions of China. The findings indicate that the digital economy exerts a more pronounced positive effect in the central

and western regions. This conclusion provides new empirical evidence for the theory of regional coordinated development and revises the one-sided view that the digital economy only plays a significant role in developed regions. The findings of this study offer policy insights for governments to formulate differentiated digital economy development strategies. First, given the significant regional heterogeneity in the impact of the digital economy on industrial structure upgrading, the central and western regions should seize the opportunities presented by the digital economy by accelerating the construction of digital infrastructure and cultivating digital talents, thereby fully leveraging their late-mover advantages. In contrast, the eastern region should focus on frontier areas of the digital economy and play a leading and demonstrative role. Second, this study confirms that human capital is an important mediating variable in the process of the digital economy driving industrial structure upgrading. Governments should prioritize the cultivation of digital talents and strengthen the alignment between education and the digital economy, enhancing the endogenous momentum for industrial structure upgrading by improving workers' digital literacy. Finally, this study highlights the potential role of the digital economy in narrowing regional disparities in industrial structure, providing theoretical support for promoting industrial upgrading in the central and western regions through digital empowerment and achieving regional coordinated development.

2. Conceptual definition and relevant theoretical analysis

Numerous domestic scholars have conducted in-depth research on the relationship between the digital economy and industrial structure. Liu pointed out that the development of the digital economy promotes the overall quality and efficiency of industrial structure by optimizing the degree of coordination among industries and enhancing their cohesion [4]. Zhao *et al.* employed a two-way fixed effects model to analyze the mechanism through which digital economy development affects industrial structure upgrading in cities within the Yellow River Basin. They found that the digital economy not only directly influences the industrial structure of the Yellow River Basin but also indirectly promotes industrial structure upgrading by enhancing the region's innovation capacity [5]. Thus, the digital economy has both direct and indirect effects on industrial structure. Luo *et al.* conducted a regional heterogeneity analysis, showing that regions with a higher degree of digital economy development experience more significant impacts on industrial structure [6]. Yu *et al.* constructed a digital economy indicator system using data from 207 prefecture-level cities in China from 2013 to 2019 and employed a difference-in-differences (DID) approach to examine the impact of digital economy policies on industrial structure upgrading. The results indicate that local government policies promoting the digital economy significantly facilitate the evolution of regional industrial structures toward greater advancement and rationalization [7].

A substantial body of domestic literature has highlighted the inextricable relationship between the digital economy and industrial structure, demonstrating that the digital economy can effectively promote industrial structure upgrading. However, relatively few studies have utilized data from all 31 provinces, autonomous regions, and municipalities directly under the central government, and even fewer have conducted mediating effect analysis and heterogeneity analysis based on the benchmark regression model. To address this gap, this study employs panel data from 31 Chinese provinces, autonomous regions, and municipalities from 2011 to 2021, selecting human capital as a mediating variable along with multiple control variables, to construct a benchmark regression model and analyze the mechanism through which the digital economy affects industrial structure. Furthermore, this study examines the mediating effect within this mechanism and finds that the digital economy indirectly influences industrial structures by accumulating more human capital. Additionally, by dividing

the 31 provincial-level regions into eastern, central, and western areas, this study analyzes regional heterogeneity and finds that the digital economy exerts varying degrees of impact on industrial structures across different regions.

3. Current status of the digital economy

This study posits that digital industrialization and industrial digitalization are equally important. Following the practices of various scholars regarding systematic weighting, equal weights are assigned to these two components [9–12]. The relevant data are then calculated to produce Figure 1.

From a holistic perspective, during the period from 2014 to 2022, all four major regions of China—except for the Northeast—exhibited an upward trend in digital economy development. As shown in Figure 1, significant regional disparities exist in China's digital economy. The eastern region outperforms the central, western, and northeastern regions in terms of digital economy development, with its performance exceeding the national average. The rapid growth of the digital economy in the eastern region can be primarily attributed to well-established infrastructure, a complete digital economy industrial chain, strong government support, and innovations in business models and formats. These factors have collectively driven the vigorous development of the digital economy in the eastern region. The digital economy levels of the western and northeastern regions were comparable in 2011; however, the western region experienced faster growth, and the gap between the two regions has since gradually widened. The slow decline observed in the digital economy of the northeastern region can be explained from the perspective of comparative economic structure. The Northeast has long been dominated by heavy and chemical industries, rendering its industrial structure relatively lagging in the context of the overarching trend of digital economy development. Issues such as technological obsolescence, a weak industrial base, and the underdevelopment of the tertiary sector have made it difficult for the industrial structure of the Northeast to adapt to the rapid growth of the digital economy. Digital talent has become a core force driving the advancement of the digital economy. Particularly against the backdrop of rapid economic development in southern China, a large number of talented individuals from the Northeast have migrated southward in search of better employment opportunities, which has, to some extent, weakened the region's innovation capacity and competitiveness. Policy environment and population aging are also contributing factors to the decline of the digital economy in the northeastern region.

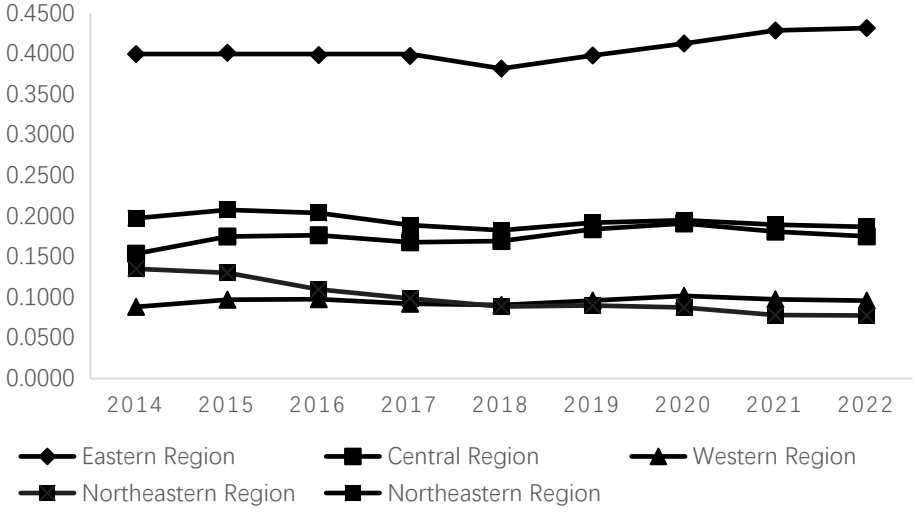

Figure 1. The development trajectory of the digital economy in China's four major regions, 2014–2022

4. Research innovations

First, this study constructs a mediating effect analysis framework of "digital economy → human capital → industrial structure upgrading," thereby deepening the understanding of the underlying mechanisms. Most existing studies focus on the direct impact of the digital economy on industrial structure upgrading, with limited exploration of its transmission mechanisms. Breaking through this limitation, this study incorporates human capital as a mediating variable into the analytical model and systematically examines the indirect pathway through which the digital economy promotes industrial structure upgrading by enhancing human capital. The results of the mediating effect test indicate that human capital accumulation serves as an important channel through which the digital economy drives industrial structure optimization. This finding reveals the internal logic of how the digital economy enables industrial structure upgrading through both direct and indirect pathways.

Second, this study comprehensively examines the effects of the digital economy from the two dimensions of industrial structure advancement and rationalization, and reveals regional heterogeneity characteristics. Most existing studies use only a single indicator to measure industrial structure upgrading, which fails to fully capture its multidimensional nature. This study adopts the ratio of tertiary industry to secondary industry output to measure industrial structure advancement, and the Theil index to measure industrial structure rationalization, and separately examines the differential effects of the digital economy on these two dimensions. On this basis, this study divides 31 provinces, autonomous regions, and municipalities into eastern, central, and western regions for group regression analysis. The results show that the digital economy has a more significant promoting effect on industrial structure upgrading in the central and western regions. This finding stands in stark contrast to the conventional view that "developed regions benefit more," revealing that the central and western regions have greater potential for industrial structure optimization through digital empowerment.

Third, this study employs a complete panel dataset of 31 provinces, autonomous regions, and municipalities in China from 2011 to 2021, enhancing the external validity of the research conclusions. Existing studies are often based on prefecture-level city data or data from only a subset of provinces, resulting in limited sample coverage. This study uses a comprehensive panel dataset covering all 31 provinces, autonomous regions, and municipalities, with a sample size of 341 observations, spanning eastern, central, western, and northeastern regions. The data sources are authoritative, and the time span is relatively long, providing good generalizability and robustness for the research conclusions. Robustness checks, including variable substitution methods, further validate the reliability of the benchmark regression results.

5. Data description

5.1. Variable selection

5.1.1. Dependent variable

The dependent variable in this study is industrial structure, the upgrading of which can be reflected in two dimensions: advancement and rationalization. Accordingly, this study adopts the following two indicators to represent industrial structure: (1) the industrial structure advancement index (y), measured by the ratio of the output value of the tertiary industry to that of the secondary industry, where a larger value indicates a higher level of industrial structure advancement; and (2) the industrial structure rationalization index (TL), where a smaller value indicates a more rational industrial structure, and the calculation formula for this index is as follows.

$$TL_{it} = \sum_{i=1}^{3} \left(\frac{Y_{ijt}}{Y_{it}} \right) ln \left(\frac{Y_{ijt}}{L_{ijt}} / \frac{Y_{it}}{L_{it}} \right) \tag{1}$$

where TL_{it} represents the industrial structure rationalization index of province i in year t, Y_{ijt} denotes the output value of industry j in province i in year t, Y_it is the total output value of province i in year t L_{ijt} is the number of employed persons in industry j in province i in year t, and L_{it} is the total number of employed persons in province i in year t (t = 1, 2, …, 11).

5.1.2. Independent variable

The independent variable in this study is the level of digital economy. Currently, numerous indicators can be used to measure the level of digital economy, which are primarily categorized into two aspects: digital industrialization and industrial digitization. Drawing on existing literature [8], this study designs the following measurement system for the level of digital economy. Specifically, four indicators—electronic information manufacturing capacity, telecommunication service capacity, internet penetration rate, and software technology level—are selected to represent the level of digital industrialization; while four indicators—new infrastructure, artificial intelligence level, digital logistics, and digital sales—are selected to represent the level of industrial digitization. See Table 1.

Table 1. Indicator system for digital economy level

First-level indicator	Second-level indicator	Third-level indicator	Attribute
Digital industrialization	Electronic Information Manufacturing Capacity	Integrated Circuit Output	Positive
	Telecommunication Service Capacity	Mobile Phone Penetration Rate	Positive
	Internet Penetration Rate	Proportion of Internet Users to Total Population	Positive
	Software Technology Level	Software Business Revenue	Positive
Industrial digitization	New Infrastructure	Length of Long-Distance Optical Cable Lines	Positive
	Artificial Intelligence Level	Number of Installed Industrial Robots	Positive
	Digital Logistics	Express Delivery Revenue	Positive
	Digital Retail	Online Retail Sales	Positive

All eight indicators are positive indicators but have different units of measurement. Therefore, the raw data need to be standardized to eliminate the effect of different dimensions on the results.

$$x_{ij}^{'} = \frac{x_{ij} - \max\left\{x_{1j}, \ldots, x_{8_j}\right\}}{\max\left\{x_{1j}, \ldots, x_{8_j}\right\} - \min\left\{x_{1j}, \ldots, x_{8_j}\right\}} \tag{2}$$

Where $x_{ij}^{'}$ denotes the data of the j-th indicator for the i-th province, with i=1,…,31； j=1,…,8. After standardizing the above eight indicators, the equal-weight assignment method is used to construct the digital economy development index DE. The specific calculation formula is as follows.

$$DE_{it} = \sum_{j=1}^{8} w_j x_{ij}^{'} (j = 1, 2, \ldots, 8 \tag{3}$$

Where DE_{it} represents the digital economy development index of province ii in year t and w_j denotes the weight of the j-th indicator.

5.1.3. Mediating variable and control variables

The digital economy can provide a high-quality labor force, thereby driving the upgrading of industrial structure. Therefore, this study selects human capital as the mediating variable (M), measured by the average years of schooling of the labor force. To more comprehensively reflect the mechanism through which the digital economy affects industrial structure, this study refers to existing literature [1] and selects the control variables shown in Table 2.

Table 2. Variable selection

Variable type	Variable symbol	Variable name	Calculation formula
Dependent Variable	y	Industrial Structure Advancement	Output value of tertiary industry / Output value of secondary industry
	TL	Industrial Structure Rationalization	$TL_{it}=\sum_{i=1}^{3}\left(\frac{Y_{ijt}}{Y_{it}}\right)ln\left(\frac{Y_{ijt}}{L_{ijt}}/\frac{Y_{it}}{L_{it}}\right)$
Independent Variable	DE	Digital Economy Level	$DE_{it}=\sum_{j=1}^{8}w_j x_{ij}^{'}$ (j=1,2,…,8)
Mediating Variable	M	Human Capital	Average years of schooling of the labor force (years)
Control Variables	GDP	Economic Development Level	Per capita gross regional product (logarithm)
	urb	Urbanization Rate	Urban population / Total population
	Inf	Infrastructure Construction	Per capita total postal and telecommunications services (logarithm)
	For	Foreign Direct Investment	FDI / GDP
	Deg	Degree of Openness	Total import and export volume / GDP
	Env	Business Environment	Marketization Index

5.2. Data sources and descriptive statistical analysis

This study selects panel data of 31 provinces, autonomous regions, and municipalities in China from 2011 to 2021 as the research objects, ultimately compiling 341 data samples. The data are sourced from the China Statistical Yearbook (2012–2022), the China Science and Technology Statistical Yearbook (2012–2022), and the website of the National Bureau of Statistics. Some individual years in certain regions have missing values, and this study employs interpolation to fill in the missing data. **Table 3** presents the descriptive statistical analysis of each variable. It can be observed that there are large gaps between the maximum and minimum values of each variable, indicating that significant differences remain in the digital economy level and industrial structure level across different regions of the country.

Table 3. Descriptive statistical analysis of variables

Variable	*n*	Mean	Std. Dev.	Min	Max
Industrial Structure Advancement	341	1.351	0.722	0.527	5.244
Industrial Structure Rationalization	341	0.216	0.196	-0.099	1.043
Digital Economy Level	341	0.600	0.067	0.486	0.886

Human Capital	341	9.196	1.084	4.666	12.701
Economic Development Level (RMB)	341	55626.590	28666.710	16024.000	183980.000
Urbanization Rate	341	0.586	0.131	0.227	0.896
Infrastructure Construction	341	0.306	0.323	0.056	1.484
Foreign Direct Investment	341	0.020	0.019	0.000	0.121
Degree of Openness	341	0.267	0.282	0.008	1.464
Degree of Openness	341	7.790	2.196	-0.160	12.922

6. Empirical analysis

6.1. Benchmark regression analysis

To analyze the impact of the digital economy on industrial structure, this study constructs the following benchmark regression models. Equation 1 takes the level of industrial structure advancement as the dependent variable, and Equation 2 takes the level of industrial structure rationalization as the dependent variable.

$$y_{it} = \alpha_0 + \alpha_1 DE_{it} + \sum_{k=1}^{6} \alpha_k control_{it} + \mu_{it} + \delta_{it} + \varepsilon_{it} \tag{4}$$

$$TL_{it} = \beta_0 + \beta_1 DE_{it} + \sum_{k=1}^{6} \alpha_k control_{it} + \mu_{it} + \delta_{it} + \varepsilon_{it} \tag{5}$$

where i represents the province, t represents the year, y_{it} denotes the industrial structure advancement index, TL_{it} denotes the industrial structure rationalization index, and DE_{it} denotes the digital economy development level. $control_{it}$ represents the control variables affecting industrial structure, μ_{it} represents individual fixed effects, δ_{it} represents time fixed effects, and ε_{it} represents the random error term.

This study uses Stata 18.0 software to construct the benchmark regression models, and the results are presented in Table 4. Columns 1 to 3 take industrial structure advancement as the dependent variable, while Columns 4 to 6 take industrial structure rationalization as the dependent variable. Columns 1 and 4 separately analyze the impact mechanism of the digital economy level on industrial structure. The results show that the digital economy significantly promotes both industrial structure advancement and industrial structure rationalization, with the most pronounced promoting effect on industrial structure advancement. Compared with Columns 1 and 4, Columns 2 and 5 include the mediating variable, namely human capital. After introducing the mediating variable, although the impact of human capital on industrial structure is relatively insignificant, the digital economy still has a significant promoting effect on industrial structure. Columns 3 and 6 further incorporate other control variables into the model. The results indicate that the coefficient of the impact of the digital economy on industrial structure increases, and its promoting effect on industrial structure upgrading remains significant. After adding the control variables, the R-squared value of the benchmark regression model also increases, indicating a significant improvement in the goodness of fit of the model.

Table 4. Benchmark regression model

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Advancement	Advancement	Advancement	Rationalization	Rationalization	Rationalization
Digital Economy Leve	7.303***	6.329***	12.101***	0.639**	0.775***	2. 601***
	(0.859)	(0.707)	(1.065)	(0.173)	(0.293)	(0.554)
Human Capital		0.097**	0.324***		0.081**	0.048***
		(0.054)	(0.061)		(0.024)	(0.017)
Economic Development Level			-0.519***			0.089*
			(0.120)			(0.050)
Urbanization Rate			-2.954***			0.514*
			(0.573)			(0.239)
Foreign Direct Investment			-0.370*			-0.264***
			(0.106)			(0.071)
Infrastructure Construction			3.336			2.437***
			(2.611)			(1.115)
Infrastructure Construction			1.354***			0.206***
			(0.138)			(0.061)
Degree of Openness			-0.147***			-0.056***
			(0.017)			(0.007)
Constant	-3.030***	-3.341***	-0.726	0.538***	-0.0579	-0.091***
	(0.497)	(0.590)	(1.142)	(0.121)	(0.154)	(0.422)
Individual/ Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	341	341	341	341	341	341
Adjusted R^2	0.451	0.462	0.746	0.334	0.111	0.409

Note: Standard errors are in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

6.2. Robustness test

This section employs the variable substitution method to conduct robustness tests, replacing the industrial structure indicators with the share of value added of the secondary and tertiary industries in GDP to analyze the impact of the digital economy on different regions. The regression results show that the digital economy development level remains significant for the substituted variables, and the sign and significance of the coefficients of the explanatory variables are consistent with the empirical results in the previous section. This indicates that the benchmark regression results of this study are robust, and the digital economy has a promoting effect on industrial structure upgrading.

Table 5. Robustness test

Variable	Industrial structure advancement	Industrial structure rationalization	Per capita regional GDP
Digital Economy Level	14.140***	1.569***	0.138***
	(0.963)	(0.245)	(0.062)
Constant	-4.268***	0.833***	0.755***
	(0.452)	(0.108)	(0.027)

Control Variables	Yes	Yes	Yes
Individual/Time Fixed Effects	Yes	Yes	Yes
Sample Size	341	341	341
Adjusted R^2	0.729	0.376	0.438

Note: Standard errors are in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

6.3. Mediating effect analysis

This section tests the mediating effect of the model. Columns 7 and 8 of Table 6 represent the impact of the digital economy on industrial structure advancement and rationalization, respectively, while Column 9 represents the impact of the digital economy on the mediating variable. The specific testing models are as follows.

$$y_{it} = \mu_0 + \mu_1 DE_{it} + \mu_{it} + \delta_{it} + \varepsilon_{it\#} \tag{6}$$

$$M_{it} = \gamma_0 + \gamma_1 DE_{it} + \mu_{it} + \delta_{it} + \varepsilon_{it} \tag{7}$$

$$y_{it} = \rho_0 + \rho_1 DE_{it} + \rho_2 M_{it} + \mu_{it} + \delta_{it} + \varepsilon_{it} \tag{8}$$

The above three models analyze the mediating effect using industrial structure advancement as an example. Here, M represents the mediating variable, namely human capital. Equation 3 is used to analyze the impact of the digital economy (DE) on industrial structure (Y), Equation 4 is used to analyze the impact of the digital economy on the mediating variable (M), and Equation 5 is used to analyze the impact mechanism of the digital economy and the mediating variable on industrial structure.

Columns 7 and 8 show that the development of the digital economy significantly promotes both the advancement and rationalization of industrial structure. Column 9 shows that the impact coefficient of the digital economy on human capital is 10.665, which is significant at the 0.05 significance level. Comparing the results of Column (7) and Column (10), it can be found that after adding human capital, the impact coefficient of the digital economy development level on industrial structure advancement remains significant. Similarly, comparing Column (8) and Column (11) also indicates that after adding human capital, the impact coefficient of the digital economy development level on industrial structure advancement remains significant. Therefore, the digital economy has both direct and indirect effects on industrial structure, and human capital serves as an important mediating mechanism.

Table 6. Mediating effect test results

Variable	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**
	Advancement	**Rationalization**	**Human Capital**	**Advancement**	**Rationalization**
Human Capital				0.075**	0.082***
				(0.0349)	(0.024)
Digital Economy Level	7.303***	0.639***	10.665***	6.791***	0.775***
	(0.859)	(0.173)	(0.768)	(0.600)	(0.293)
Constant	-3.030**	0.538***	2.879***	-3.390***	-0.0579
	(0.497)	《0.121》	(0.458)	(0.298)	《0.154》
Individual/Time Fixed Effects	Yes	Yes	Yes	Yes	Yes
Sample Size	341	341	341	341	341
Adjusted R^2	0.451	0.175	0.383	0.459	0.112

Note: Standard errors are in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

6.4. Regional heterogeneity analysis

To analyze the impact of the digital economy on industrial structure in different regions, this section divides 31 provinces, autonomous regions, and municipalities into eastern, central, and western regions, and conducts benchmark regression analyses separately. The results are shown in Table 7. The coefficients of the digital economy level in all three regions are positive. However, the impact of the digital economy on industrial structure rationalization in the eastern region is not significant. The reason may be that the economic level of the eastern region has obvious advantages compared with other regions, and the industrial structure in the eastern region has already tended toward rationalization, so the promoting effect of digital economy development on industrial structure rationalization is limited. The central region exhibits the most significant impact, as it has a better industrial foundation compared with the western region, which can provide better support for the role of the digital economy. In contrast, the western region may experience bipolarization or multipolarization issues during the development of the digital economy, leading to unbalanced industrial development.

Table 7. Regional heterogeneity test results

Variable	Eastern region		Central region		Western region	
	Advancement	Rationalization	Advancement	Rationalization	Advancement	Rationalization
Digital Economy Level	10.40***	0.142	4.755***	0.729***	1.578***	0.944***
	(0.884)	(0.368)	(0.421)	(0.130)	(0.401)	(0.118)
Constant	-4.938**	0.148	-1.655***	0.585***	0.317	0.781***
	(0.566)	(0.236)	(0.244)	(0.076)	(0.235)	(0.069)
Individual/Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Sample Size	121	121	88	88	132	132
Adjusted R^2	0.534	0.227	0.592	0.259	0.099	0.324

Note: Standard errors are in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

7. Conclusion and recommendations

7.1. Research conclusions

Based on panel data of 31 provinces, autonomous regions, and municipalities in China from 2011 to 2021, this study analyzes the impact mechanism and internal logic of the digital economy on industrial structure. The findings indicate that the digital economy significantly promotes the upgrading of industrial structure across the country, effectively driving both the advancement and rationalization of industrial structure. The mediating effect test shows that the accumulation of human capital is an important channel through which the digital economy drives industrial structure upgrading in China. Furthermore, the effect of the digital economy on industrial structure varies across different regions. The regional heterogeneity test reveals that the digital economy has a more pronounced promoting effect on industrial structure upgrading in the central and western regions, while its impact on the eastern region is relatively less significant. Therefore, the impact of the digital economy on industrial structure across the country exhibits a pattern of being stronger in the eastern region and weaker in the western region.

7.2. Policy recommendations

7.2.1. Promoting the development of the digital economy to facilitate industrial structure upgrading

Promoting the development of the digital economy and facilitating industrial structure upgrading require the joint efforts of the government, enterprises, and all sectors of society. By strengthening the construction of digital infrastructure, promoting the development and utilization of data resources, advancing the digital transformation of industries, cultivating new business models and formats of the digital economy, enhancing the cultivation of digital talents, improving the governance system of the digital economy, and deepening the integration of the digital economy and the real economy, the development of the digital economy can be effectively promoted. This will, in turn, facilitate industrial structure upgrading and achieve sustained and healthy economic development.

7.2.2. Increasing scientific and technological innovation to improve industrial production efficiency

Scientific and technological innovation is the core driving force for improving industrial production efficiency. By strengthening investment in scientific research, cultivating innovative talents, promoting industry-university-research cooperation, and optimizing the innovation environment, the innovation vitality of enterprises can be stimulated, and the sustainable development of scientific and technological innovation can be promoted, providing strong support for industrial upgrading and economic development. For example, the application of intelligent manufacturing technology can achieve precise control and optimized scheduling of production processes, improving the flexibility and response speed of production lines. The introduction of Internet of Things (IoT) technology can enable remote monitoring and fault warning of production equipment, reducing equipment failure rates and minimizing downtime.

7.2.3. Adjusting digital economy development strategies according to regional development conditions

The impact of the digital economy on industrial structure varies across different regions, and significant differences exist in the economic development conditions of different regions. Therefore, each region should fully consider its own industrial characteristics, applicable resources, and other factors when formulating different digital economy development strategies, and should pay attention to the cross-sectoral flow of production factors. The country also needs to make rational use of big data-related technologies for the overall planning of digital economy development across regions, so as to make the allocation of resources in each region more rational.

Disclosure statement

The author declares no conflict of interest.

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