Digital economy innovation, technological progress and Chinese industrial structure upgrading

Shuguang Feng

School of Economics, Harbin University of Commerce, Harbin, Heilongjiang, 150028, China

fsg398355225@163.com

Abstract. Based on the panel data of 31 provinces in China from 2011 to 2020, this paper constructs a digital economy innovation system to measure the development level of digital economy innovation, and uses the mediation effect model to test the mechanism of digital economy innovation on industrial structure upgrading. The results show that: (1) there is a "U" shaped relationship between digital economy innovation and industrial structure rationalization, and an inverted "U" shaped relationship between digital economy innovation and industrial structure premiumization; (2) Digital economy innovation can significantly promote technological progress; (3) Digital economy innovation can promote the advanced industrial structure through technological progress, and does not have a significant transmission effect on the rationalization of the industrial structure. Based on this, the development of digital infrastructure should be coordinated in an overall manner, the construction of digital platforms should be promoted, and differentiated and flexible digital development policies should be formulated for different regions and industries.

Keywords: digital economy innovation; technological progress; industrial structure upgrading; Mediation effect

1 Introduction

With the wave of digital economy sweeping the world, China has made breakthroughs in the development of the Internet, artificial intelligence, big data and other aspects, and the digital economy has become a key driver to promote the high-quality development of China's economy and the modernization of industrial structure. In December 2021, the 14th Five-Year Plan for the Development of the Digital Economy issued by the State Council placed a high emphasis on vigorously deepening the digitalization of enterprises and the digital transformation of industries, and greatly improving the ability of digital innovation to lead development, which shows that the innovative development of the digital economy will have a profound impact on the upgrading of the industrial structure that relies on technological progress. Therefore, studying the role and mechanism of digital economy innovation on industrial structure upgrading is of far-reaching significance.

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2 Literature review

The digital economy was first pointed out by the American economist Tapscott Don (1996) as a new economic form brought about by the development of the Internet[1]. With the rapid development of the information economy and the Internet, the digital economy is defined as an upgrade and extension of the two, essentially socio-economic activities related to big data, information technology and the Internet (Georgiadis C.K., 2013)[2] Digital economy innovation is not clearly defined in academia at present, but it is essentially a technological innovation system, superimposed on the network and platform characteristics of the digital economy, making digital economy innovation ecological and clustered, which can evolve through two nonlinear mechanisms of change and selective retention (Bongsug Kevin) Chae, 2019) [3].

In the process of the evolution and upgrading of the industrial structure, the progress of science and technology can optimize the industrial structure by promoting the positive development of labor productivity and industry scale (Ngai, 2007) [4], with the rapid development of the digital economy, the digital economy has already subtly penetrated into social and economic activities, which can not only promote the birth of new formats and industries (Pradhan, 2019) [5], but also transform production factors through the integration of digital technology and traditional industries. Thereby optimizing the allocation of resources and promoting the transformation of production methods and structures (Laudien, 2019) [6]

3 Mechanism analysis and hypothesis

3.1 Direct effect impact

As a part of the innovation-driven system, digital economy innovation can promote the association and reorganization of traditional elements and extend the boundary of innovation subjects to achieve effective allocation of resources, and at the same time promote the change of information knowledge transmission and acquisition mode, optimize the resource supply and demand matching mode of traditional industries, realize the digitalization of traditional industries and the development of emerging industries, and promote industrial transformation and upgrading[7]. From the perspective of economic costs, data is not only highly liquid, but also not constrained by time and space, based on which digital innovation activities can reduce the cost of search, transportation and other costs in digital economic activities and strengthen the connection between various industrial chains. As the core of digital economy innovation, digital technology innovation can break geographical barriers and accelerate the cross-regional flow of traditional production factors, so as to accelerate the coordinated development of upstream and downstream enterprises and promote technological exchanges. Based on this, this paper proposes the following assumptions:

Hypothesis 1: Digital economy innovation can directly promote the upgrading of industrial structure, and there is a "U" shaped relationship with the rationalization of

industrial structure, and a "U" shaped relationship with the advanced industrial structure.

3.2 Indirect effects

Digital economy innovation activities accelerate the cross-spatial flow of information and knowledge, solve problems such as information asymmetry and non-circulation of resources between markets and enterprises, and provide a networked platform to promote technological innovation of enterprises and upstream and downstream of the industrial chain to achieve technological progress[8]. Digital technology can optimize the market structure and promote the upgrading of the industrial structure, not only that, technological progress can play a key role in the innovation of traditional products and processes, and then give birth to a higher level of industrial form. Based on this analysis, the following hypotheses are proposed:

Hypothesis 2: Digital economy innovation can indirectly promote industrial structure upgrading by influencing technological progress.

4 Study design

4.1 Key variable selection and measurement

(1) The variable to be explained - industrial structure upgrading (STR). This paper measures from two aspects: industrial structure rationalization (TL) and industrial structure advanced (IND), in which the ratio of the added value of the tertiary industry to the added value of the secondary industry is used to measure the advanced industrial structure. The rationalization of the industrial structure is measured using the Thiel coefficient, namely:

$$TL_{it} = \sum_{m=1}^{3} \frac{Y_{itm}}{Y_{it}} ln(\frac{Y_{itm}}{L_{itm}} / \frac{Y_{it}}{L_{it}})$$

In this formula, the m value represents industries I., II. and III. respectively, Y represents the GDP of a certain region, and L represents the number of employed people;

(2) The core explanatory variable – the level of innovation (DET) in the digital economy[9][10].This is shown in Table 1.

Table 1. Digital economy innovation level price index system

Level 1 indicators	Secondary indicators	Tertiary indicators
The level of innovation in the digital economy	Digital infrastructure	Number of mobile phone base stations (10,000)
		Mobile phone penetration rate (per 100 people)
		Number of Internet broadband access ports (10,000)
	Digital industrialization	Software Industry Revenue (million yuan)
		Total output value of information service industry (100 million yuan)

		Telecommunications business volume (100 million yuan)
		Technical contract turnover (million yuan)
	Digital technology innovation	Number of invention patents (pieces)
		Number of R&D projects of industrial enterprises above designated size

(3) Mediating variable – technological progress (TFP). This study uses total factor productivity as a measure of technological progress.

(4) Financial Development Level (FIN), Government Fiscal Intervention (GOV), Human Resource Level (HUM) and Urbanization Level (TOWN). The ratio of financial loan balance to GDP, the ratio of local fiscal expenditure to GDP, the ratio of the number of students enrolled in higher education to the total population of the city at the end of the year, and the ratio of the agricultural population to the total population were used to measure respectively.

4.2 Model Settings

This section focuses on whether digital economy innovation can promote industrial structure upgrading, and in order to verify the hypothesis proposed above1, the following benchmark regression model is constructed:

$$TL_{it} = \beta_0 + \beta_1 DET_{it} + \beta_2 DET_{it}^2 + \sum_{j=3}^{n} \beta_j X_{it}^j + \mu_{it} + \varepsilon_{it} \quad (1)$$

$$IND_{it} = \beta_0 + \beta_1 DET_{it} + \beta_2 DET_{it}^2 + \sum_{j=3}^{n} \beta_j X_{it}^j + \mu_{it} + \varepsilon_{it} \quad (2)$$

β0 is a constant term, X represents four control variables, μ control individual effect, ε represents the residual term.

4.3 Data Sources

The research object of this study is 31 provinces in China except Tibet, and the original numbers corresponding to each index from 2011 to 2020 are collected through the data published by the China Statistical Yearbook and the statistical bureaus of various provinces and cities, and the missing data of individual indicators are used by linear interpolation method.

5 Empirical analysis

5.1 Descriptive statistical and metrological tests

Table 2. Descriptive statistics of variables

Variable	Obs	Mean	Std. Dev.	Min	Max
TL	300	0.22	0.20	0.01	1.04
IND	300	1.32	0.73	0.53	5.24
IU	300	1.22	0.70	0.52	5.30

DET	300	-0.004	0.19	-0.31	1.14
DET2	300	0.034	0.11	0.001	1.30
TFP	300	1.64	0.75	0.16	2.90
FIN	300	3.23	1.15	1.52	8.13
GOV	300	0.25	0.103	0.11	0.64
HUM	300	0.02	0.01	0.01	0.04
TOWM	300	0.59	1.22	0.35	0.90

In Table 2, The VIF values of the variables are less than 10, so there is no collinearity problem of the variables. At the same time, the Hausman test results reject the null hypothesis of "random effects", so the model adopts a fixed-effect model.

5.2 Empirical analysis of impact relationships

A fixed-effect model was used to examine the impact relationship between the two and the results are presented in Table 3.

Table 3. Panel regression results of digital economy innovation and industrial structure upgrading, rationalization and premiumization

variable	TL		IND	
	（1）	（2）	（3）	（4）
DET	-0.166* （-1.87）	-0.1147 （-1.54）	1.2445*** （5.34）	0.8262*** （5.23）
DET2	0.0593 （0.56）	0.1631* （1.90）	-0.6039** （-2.19）	-0.7352*** （-4.04）
FIN		-0.1393*** （-6.82）		0.171*** （3.95）
GOV		1.326*** （4.70）		1.3729** （2.30）
HUM		- 16.2884*** （-3.85）		-0.2649 （-0.03）
TOWM		0.5256** （2.25）		2.4277*** （4.91）
Constant terms	0.221*** （33.50）	0.3513*** （4.05）	1.3505*** （77.89）	-0.9707*** （-5.28）
Control variables	NO	YES	NO	YES
N	300	300	300	300
R2	0.1342	0.1626	0.0778	0.5431

Note: () is the t statistic, [] is the statistic adjoint probability; Indicates that the p-value < 0.01, ** means that the p-value < 0.05, and * indicates that the p-value < 0.1. Same below.

In Table 3, From the columns (1) and (3), it can be seen that the coefficient of digital economy innovation is significant at the significance level of 1%. (2) The quadratic term coefficient of digital economy innovation in the column is significantly positive at the significance level of 10%, and the extreme value point is 0.351, and the quadratic

term coefficient in the column (4) is significantly negative at the significance level of 1%, so the assumption 1 is true. Possible reasons are: the background of digital economy innovation is the era of big data, with informatization, intelligence, etc. as the basis for development, the early technological optimization has a positive effect on the advanced industrial structure, but the positive effect brought by the low level of industrial structure or traditional industries is insufficient, coupled with the different degrees of dependence on digitalization in the development of the central and western regions, so the early digital economy innovation inhibits the rationalization of the industry, and the degree of industrial digitalization increases in the later stage. The optimization of knowledge resource allocation brought about by digital economy innovation will promote the rationalization of industrial structure. In addition, it can be seen from columns (2) and (4) that the four control variables have a significant impact on the rationalization and upgrading of industrial structure.

5.3 Mediation Effect Test

In order to test the mediating effect on technological progress, this paper constructs the following mediating effect model:

$$TFP_{it} = \beta_0 + \beta_1 DET_{it} + \beta_2 DET_{it}^2 + \sum_{j=3}^{n} \beta_j X_{it}^j + \mu_{it} + \varepsilon_{it} \quad (3)$$

$$TL_{it} = \beta_0 + \beta_1 DET_{it} + \beta_2 DET_{it}^2 + \sum_{j=3}^{n} \beta_j X_{it}^j + \beta_3 TFP_{it} \mu_{it} + \varepsilon_{it} \quad (4)$$

$$IND_{it} = \beta_0 + \beta_1 DET_{it} + \beta_2 DET_{it}^2 + \sum_{j=3}^{n} \beta_j X_{it}^j + \beta_3 TFP_{it} \mu_{it} + \varepsilon_{it} \quad (5)$$

The results of the mediating mechanism for technological progress are summarized in Table 4.

Table 4. Results of the regression of mediating effects of digital economy innovation and rationalization and advanced industrial structure upgrading

variable	TFP （1）	TL （2）	IND （3）
DET	0.8685* （1.14）	-0.1141 （-1.52）	0.8449*** （5.35）
DET2	0.2538 （0.29）	0.1629* （1.89）	-0.7406*** （-4.08）
TFP		0.0006 （0.11）	0.0214* （1.69）
FIN	-0.3326 （-1.59）	-0.1391*** （-6.67）	0.1782*** （4.11）
GOV	1.19 （0.41）	1.3252*** （4.69）	1.3473** （2.26）
HUM	-149.198*** （-3.45）	-16.1938*** （-3.74）	2.9388 （0.32）
TOWM	6.4423***	0.5215**	2.2894***

	（2.70）	（2.20）	（4.59）
Constant terms	1.5936**	0.3503***	-1.005***
	（1.80）	（4.01）	（-5.45）
Control variables	YES	YES	YES
N	300	300	300
R2	0.0847	0.1629	0.5517

It can be seen from Table 4 that the coefficient of digital economy innovation in column (1) is significantly positive at the implementation level of 10%, so digital economy innovation has a significant positive effect on technological progress; (2) The quadratic coefficient of digital economy innovation in the column is significantly positive at the confidence level of 10%, but there is no significant correlation between technological progress and industrial structure rationalization. (3) The primary term coefficient of digital economy innovation in the column is 0.8449 (t=5.35), which is significant at a confidence level of 1%, the quadratic term coefficient is -0.7406 (t=-4.08), and it is significant at a confidence level of 1%, and the TFP coefficient is 0.0214 (t=1.69), which is significant at a confidence level of 10%, so digital economy innovation can only promote the advanced industrial structure through technological progress. Possible reasons are: the economic benefits brought by technological progress are mainly concentrated in emerging and high-tech industries, and the promotion effect on some traditional industries is not obvious, and at the same time, technological agglomeration is formed among innovative enterprises, resulting in polarization that is not conducive to the rationalization of industrial structure.

6 Conclusions and implications

6.1 Conclusions

Digital economy innovation can promote industrial structure upgrading, and the research conclusions show that: (1) the relationship between digital economy innovation and industrial structure rationalization is "U"-shaped, that is, in the short term, digital economy innovation inhibits the rationalization of industrial structure, and with the increase of industrial digitalization, it will play a role in promoting the rationalization of industrial structure; (2) The inverted "U" shaped relationship between digital economy innovation and industrial structure premiumization, that is, it will have a positive effect on the advanced industrial structure in the early stage, and the marginal effect will decrease with the technological progress of enterprises; (3) Digital economy innovation can significantly promote technological progress and promote the advanced industrial structure through technological progress, but due to the effect of technological agglomeration, it has failed to promote the rationalization of industrial structure through technological progress.

6.2 Research implications

First of all, we should promote the construction of digital infrastructure and digital platforms. Digital infrastructure is the foundation of the innovation and development of the digital economy, and the government should coordinate the overall layout, and further promote the construction of digital infrastructure such as 5G base stations and communication networks, while actively deploying the construction of digital cloud platforms such as the Internet of Things, cloud computing and big data, promote the interconnection of knowledge resources, and provide a steady stream of impetus for the innovation and development of the digital economy.

Second, we should guide the coordinated development of digital economy innovation. Based on the development level of digital economy development in various regions, formulate appropriate digital economy innovation and development policies. At the same time, it pays attention to the development differences between various industries, implements dynamic policies that conform to different stages of industrial development, promotes the digitalization of traditional industries, and promotes the integrated development of digital technology and technology-intensive industries to promote the rational development of industrial structure.

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