Frontiers in Business, Economics and Management
ISSN: 2766-824X | Vol. 7, No. 1, 2023

Research on the Impact of Digital Economy on Industrial Energy Efficiency

Wei Li

School of Business, Hunan University of Science and Technology, Xiangtan, Hunan 411201, China

Abstract: Under the background of "dual control" of total and intensity of energy consumption in China, improving energy efficiency has become an important topic in China's economic development. The penetration effect, synergy effect and substitution effect of digital economy on industry have brought about great changes in the industrial development model, which may have an impact on energy efficiency. Based on the analysis of the mechanism of the effect of digital economy on industrial energy efficiency and the panel data of 280 cities in China, this paper empirically analyzes the impact of digital economy development on industrial energy efficiency. The empirical results show that digital economy promotes the improvement of industrial energy efficiency. The intermediate mechanism is that digital economy realizes the improvement of energy efficiency through the integration of production and marketing and accelerating the substitution of data elements for power resources elements, which is more significant in cities with high levels of economic development, innovation and industrial structure.

Keywords: Digital economy, Industrial energy efficiency.

1. Introduction and Literature Review

Promoting high-quality economic development has become China's current primary goal, and building a resource-saving and environment-friendly society is an important task.[1]. Under the background of the unprecedented development of digital economy, industry digitalization and digital industrialization have become the current mainstream. The large-scale construction of industrial Internet and smart factories makes digital economy a feasible path for the construction of green China.[2].

Promoting the integration of digital technology and traditional industry can effectively eliminate the unnecessary waste of resources and energy and reduce environmental pollution.[3]. There are two specific ways for digital economy to boost industrial energy efficiency. On the one hand, enterprises apply digital technologies such as big data, internet of things and distributed management to the energy consumption monitoring and scheduling process of production equipment to monitor the energy consumption of each production link, thus enabling equipment with different energy consumption standards to achieve efficient energy scheduling, avoiding unnecessary energy waste and improving energy efficiency[4]. On the other hand, with the support of high-precision equipment, enterprises can improve the accuracy and product quality of product parts production, ensure the product qualification rate, reduce energy consumption from the product level and improve energy efficiency[5].

On the theme of the impact of digital economy on the green development of industry, domestic literature has carried out research from the aspects of pollution control and energy intensity. Some scholars use SO2 removal rate, comprehensive utilization rate of industrial solid waste and PM2.5 as indicators of urban environmental governance results, and finds that digital economy will achieve high-quality urban development[6]. Some scholars believe that the development of digital economy can reduce the degree of environmental pollution by promoting the upgrading of urban industrial structure, and this effect is more significant in less developed areas.[7]. Some scholars find that informatization reduces the industrial energy intensity through the substitution effect of factors.[8] Some scholars use enterprise survey data to demonstrate that there is a significant negative relationship between informatization degree and enterprise energy intensity[9]. The above studies only focus on the green benefits of digital economy from the aspects of pollution control or energy consumption of digital economy development, and do not include industrial output value as economic benefits in the interpreted variable indicators. Therefore, this paper uses labor and energy consumption as inputs, industrial output value and pollutants as outputs to measure the total factor energy efficiency including undesired outputs, and uses this as an explanatory variable index to conduct research on the green effect of digital economy, which may produce certain marginal contribution.

Regarding the research on total factor energy efficiency including pollutants, some scholars use the SBM model to conduct an empirical analysis on the environmental efficiency of China's industries. It is found that the heavy economic structure and the large scale of industrial enterprises will lead to low efficiency.[10]. Some scholars use enterprise data to prove that manufacturing agglomeration inhibits the improvement of enterprise total factor energy efficiency, and also intensifies the technological progress bias of capital over energy[11]. Some scholars estimated the total factor energy efficiency of 30 provinces in China, and demonstrated that the carbon trading policy acts on industrial structure, technological innovation and energy structure, so as to improve the total factor energy efficiency.[12]. Some scholars empirically test the contribution of digital economy to total factor energy efficiency by promoting inter-provincial market trade, import and export, etc [13]. Some scholars empirically test that the low-carbon city pilot policy has significantly improved the total factor energy efficiency by optimizing the industrial structure and promoting technological innovation[14].

Based on these, from the perspective of total factor energy efficiency, this paper analyzes the impact of digital economy development on total factor energy efficiency and its mechanism. Taking the data of 280 prefecture-level cities in China from 2011 to 2019 as a sample, this paper empirically tests the impact of digital economy development on total factor energy efficiency. The marginal contribution of this paper may be reflected in two aspects: first, the three pollutants such as industrial sulfur dioxide emissions, industrial waste solid emissions and industrial wastewater emissions are included in the total factor energy efficiency index as the unexpected outputs, which are used as the explanatory variables to analyze the green effect of the digital economy. Therefore, this paper provides incremental evidence for the analysis of the green effect of the digital economy. Secondly, this paper investigates the transmission mechanism of digital economy development affecting total factor energy efficiency in detail, and puts forward the path of industrial intensification, production and marketing integration and factor substitution mechanism combined with the characteristics of digital economy, which enriches the research field of green effect of digital economy.

2. Theoretical Analysis and Research Hypothesis

2.1. Direct effect of digital economy on total factor energy efficiency

The direct impact of the development of digital economy on energy efficiency is mainly reflected in the improvement of skills and technology in the production process, energy monitoring and scheduling of production equipment, etc. After the completion of the digital transformation, the production automation level of enterprises has been improved unprecedentedly. With the support of modern intelligent production machines, the production of enterprises has a stronger stability, reducing the probability of defective products and reducing the energy waste. In the production process, enterprises rely on digital technology for production process improvement and equipment renewal to improve energy utilization efficiency and energy recycling rate. After the introduction of the digital platform, the fast feature of the digital economy enables the real-time sharing of production information of various departments of the enterprise, improves the exchange efficiency of enterprise information, promotes the rational allocation of production resources, and thus improves the energy efficiency.

2.2. The mediating effect of digital economy on total factor energy efficiency

With the support of digital technology, the communication between enterprises is direct, the economic organization structure gradually tends to be flat, the contact between consumers and producers is strengthened, the transaction cost is greatly reduced, and the storage, transportation and advertising of middlemen are also extremely reduced, thus improving the energy efficiency. At the same time, enterprises use digital technology to build their own network platform to realize self-production and self-sale of products.[15]

Digital technology enables the primary and secondary industries, continuously blurs the boundaries of the three industries, and promotes the integration of the three industries.Secondly, the digital economy takes data as its core element. The use and accumulation of data not only have incremental marginal benefits, but also can substitute tangible resources and energy.[16] After the enterprise completes the digital transformation, the enterprise's investment in digital technology and data collation and analysis increases, while the investment in energy is relatively reduced. Factor substitution is formed between data and energy, which not only ensures the original production capacity but also reduces the energy input, improves the energy efficiency and reduces the generation of pollutants. In addition, the development of digital economy has greatly improved the intelligence level of enterprise production.[17]The construction of "unmanned factory" and "black light factory" has become an important goal of enterprise development. The input of labor force is gradually reduced, and the energy factors used to maintain the labor force production work are also reduced. Factor substitution is formed between data and labor force.

3. Research and Design

3.1. Data sources

Based on the principles of data availability and integrity, this paper uses the balanced panel data of 280 prefecture-level cities from 2011 to 2019 for empirical analysis, and a small number of missing values are filled by moving average method. The data are mainly from China City Statistical Yearbook and EPS database.

3.2. Variable selection

The specific conditions of the explained variables, core explained variables and control variables in this paper are as follows:

Interpreted variable: total factor energy efficiency eff. Referring to the practice of Some scholars, factors such as industrial output value, energy consumption and pollutant emissions of 280 cities are included in the measurement index, and the SBM total factor energy efficiency index of 280 cities in the country from 2011 to 2019 is calculated by MATLAB.

Core explanatory variable: digital economy development level (*lndig*).Referring to the practice of Some scholars, the digital economy development level index of each city is calculated by integrating the relevant digital economy indicators of each city.

Control variables: referring to the existing literature, this paper takes the economic development level, population size, fixed assets investment scale and government revenue and expenditure of each city as control variables to be included in the measurement model. specifically, this paper uses per capita GPD to represent the level of urban economic development, uses the number of permanent residents at the end of the year to measure the size of urban population, uses the total fixed assets investment to measure the size of urban fixed assets investment, and uses government expenditure and income to measure the government revenue and expenditure.

3.3. Model establishment

In order to test the hypothesis that the development of digital economy will promote the improvement of industrial energy efficiency, this paper constructs the following measurement model:

$$eff_{it} = \alpha + \beta_1 lndig_{it} + X_{it} + \mu_i + \tau_t + \varepsilon_{it}$$

Among them, α is a constant term, β_1 is a regression coefficient, $lndig_{it}$ is the digital economic development level index of city i in t year, X_{it} is a series of control variables, μ_i is the individual fixed effect of city, τ_t is the year fixed effect so as to eliminate the influence of other cities and time changes, ε_{it} is a random disturbance term.

4. Empirical Results and Analysis

4.1. Analysis of benchmark regression results

Table 1, column (1), reports the OLS estimation results of the model, which shows the impact of the development of digital economy on industrial energy efficiency. After incorporating the control variables and performing fixed effect regression, the results are still significantly positive as shown in column (2), indicating that the development of digital economy has a certain promoting effect on industrial energy efficiency. From the perspective of control variables, the level of urban economic development and government expenditures are all coordinated with digital economic technology to promote the improvement of industrial energy efficiency, while government revenue, i.e. tax revenue, will lead to an increase in the production and operation costs of enterprises, which is not conducive to enterprises' investment in energy efficiency improvement and inhibits the improvement of industrial energy efficiency.

Table 1. Benchmark Regression Results

Interpreted variable	(1) OLS eff	(2) Fixed effect eff
lndig	0.015***	0.005*
	(0.003)	(0.003)
pgdp		0.001***
		(0.001)
hum		0.001
		(0.001)
invest		0.001
		(0.001)
govpay		0.001***
		(0.001)
govincome		-0.001***
		(0.001)
_cons	0.544***	0.581***
	(0.024)	(0.028)
N	2520	2520
R^2	0.013	0.067

Note: T values are shown in brackets, and *, * * and * * * represent significance levels of 10%, 5% and 1%, respectively. The following tables are the same.

4.2. Robustness test

In order to verify the robustness of the above conclusions, this paper tests the robustness of the above regression results and performs regression again by replacing the explained variables. In the aspect of variable selection, this paper uses the proportion of industrial electricity consumption to replace the index of industrial energy efficiency. While the industrial output value is steadily increasing, the proportion of industrial electricity consumption is continuously decreasing, which indicates that the industrial energy efficiency has been improved. Therefore, it is reasonable to choose the proportion of industrial electricity consumption as an alternative index of robustness test. Specific method: the ratio of industrial electricity consumption to (industrial electricity consumption+domestic electricity consumption) is used as the explained variable to measure the proportion of industrial electricity consumption, and then fixed effect regression is performed. The test results are shown in Table 2. As can be seen from Table 2, the regression results are still significant after the explanatory variables are replaced, and the reliability of the above conclusions is verified.

Table 2. Robustness Test

Interpreted variable	enper
lndig	-0.014***
	(0.004)
_cons	0.888***
	(0.038)
N	2520
R^2	0.174

5. Mechanism Test and Heterogeneity Analysis

5.1. Mechanism testing

In the benchmark regression and robustness test above, it is proved that the development of digital economy has a promoting effect on industrial energy efficiency. Based on the above theoretical analysis, this paper argues that the digital economy mainly promotes the integration of production and marketing of industrial enterprises and the substitution of factors to achieve the improvement of industrial energy efficiency. In order to test the above-mentioned mechanism, this paper uses an intermediate effect model to conduct an empirical test.[18]The mediating effect model is as follows:

$$Y_{it} = \alpha_0 + \alpha_1 lndig_{it} + \gamma X_{it} + \mu_i + \tau_t + \varepsilon_{it}$$
$$M_{it} = \beta_0 + \beta_1 lndig_{it} + \gamma' X_{it} + \mu_i + \tau_t + \varepsilon_{it}$$
$$Y_{it} = \theta_0 + \theta_1 lndig_{it} + \theta_2 M_{it} + \gamma'' X_{it} + \mu_i + \tau_t + \varepsilon_{it}$$

M is an intermediate variable, *X* is a control variable, and *Y* is an interpreted variable. According to the principle of mediating effect test, if α_1, β_1 and θ_2 all pass the significance test, and the absolute value of θ_1 coefficient becomes smaller or the significance level decreases relative to α_1, then there is mediating effect among the variables.

The results obtained after regression of the mediating effect model are shown in Table 3. Items (1), (2) and (3) are listed as the empirical results of Mechanism 1. Mechanism 1 uses the logarithm (*lnpost*) of the total postal business as an intermediate variable. After the development of digital economy, industrial enterprises use digital technology to sell products through online channels, and conduct business docking and settlement in the form of network, which greatly improves the efficiency of product supply among enterprises, solves the problems of overcapacity and overstock, and can customize products according to customer demand, improves the qualification rate of products, avoids energy consumption in the storage and production of products and raw materials of industrial enterprises, and improves energy efficiency. Items (4), (5) and (6) are listed as the empirical results of Mechanism 2. Mechanism 2 uses the proportion of industrial electricity consumption (*enper*) as an intermediate variable. Industrial enterprises use digital technology to monitor the energy consumption of machinery and equipment in production, and make reasonable energy scheduling for high-energy consuming links and redundant links, so as to reduce the energy waste in production links and thus improve the energy efficiency of industrial production. This shows that after the development of digital economy to a certain scale, enterprises replace the energy factor with data as the new factor of production, and integrate with each major factor of production to realize the improvement of energy efficiency.

Table 3. Mechanism Analysis

	Integration of production and marketing			Element substitution		
	(1)	(2)	(3)	(4)	(5)	(6)
lndig	0.0051*	0.2782***	0.0029	0.0051*	-0.0142***	0.0030
	(0.0029)	(0.0378)	(0.0029)	(0.0029)	(0.0039)	(0.0028)
lnpost			0.0078***			
			(0.0016)			
enper						-0.1432***
						(0.0154)
N	2520	2520	2520	2520	2520	2520
R^2	0.0664	0.4543	0.0761	0.0664	0.1736	0.1012

5.2. Heterogeneity analysis

The above proves that the development of digital economy can promote the improvement of industrial energy efficiency, but for different types of cities, is there heterogeneity in this promotion effect?

5.2.1. Heterogeneity of industrial structure

This paper takes the average value of each city's industrial upgrading index from 2011 to 2019 as the grouping basis. If the city's industrial upgrading index is higher than the average value, it is classified as "city with higher industrial level", otherwise it is classified as "city with lower industrial level". The industrial upgrading index in this paper adopts the measurement method of Some scholars. The higher the index, the higher the local industrial structure level[19]. Columns (1) and (2) in Table 4 report the estimation results of the two groups respectively. It can be seen that the development of digital economy plays a more significant role in promoting industrial energy efficiency in cities with higher levels of industrial structure, while the development of digital economy cannot promote the improvement of industrial energy efficiency in cities with lower levels of industrial structure. Cities with high levels of industrial structure have more technology-intensive and capital-intensive industries. High-technology-intensive industrial enterprises can quickly integrate advanced digital technology into production, thus enabling digital economy and technology to better play the role of energy conservation in these high-level industries [20].

Table 4. Heterogeneity Analysis

	Industrial structure		Innovation level		urban size	
	high	low	high	low	big	small
	(1)	(2)	(3)	(4)	(5)	(6)
lndig	0.0088*	-0.0029	0.0068*	-0.0018	0.0079**	-0.0002
	(0.0049)	(0.0036)	(0.0039)	(0.0040)	(0.0034)	(0.0040)
N	1207	1313	1216	1304	998	1522
R2	0.0624	0.0790	0.0813	0.0851	0.1940	0.0626

5.2.2. Heterogeneity of innovation level

The digital economy itself is the product of a series of emerging technologies. The improvement of the city's innovation level is conducive to technological progress and promotes the development of the digital economy industry itself.[21] Based on the average number of urban patent applications as a grouping basis, this paper classifies cities with patent applications above the average number as cities with high innovation level, and vice versa as cities with low innovation level. Columns (3) and (4) in Table 4 report the regression results of the two groups. From the regression results, it can be seen that the digital economy plays a significant role in improving industrial energy efficiency in cities with high innovation level, while this role is not significant in cities with low innovation level. This shows that the energy-saving effect of the digital economy depends not only on the development of the digital economy itself, but also on the improvement of urban innovation level.

5.2.3. Heterogeneity of city size

The digital economy itself follows Metcalfe's law and has self-expansion and external economy. The increase of network users makes the benefits brought by the digital economy grow exponentially.[22]. With the support of digital economy and technology, industrial enterprises realize the integration of production and marketing and connect consumers with producers. Therefore, the larger the city scale, the greater the release of digital economy dividend. Based on the average of the total population at the end of the year, this paper defines a city with a total population above the average as a large-scale city and vice versa. Table 4 (5) and (6) are grouped regression results. It can be seen from the results that the development of digital economy plays a significant role in improving industrial energy efficiency in larger cities, while it is not significant in smaller cities. This indicates that the energy-saving effect of digital economy also plays a role around population agglomeration.

6. Conclusions and enlightenment

The research results of this paper show that the development of digital economy is beneficial to the improvement of industrial total factor energy efficiency. Through the mechanism analysis of intermediary effect, the development of digital economy improves energy efficiency by promoting the integration of enterprise production and marketing and the substitution of production factors. At the urban level, the promotion effect of the development of digital economy on energy efficiency is heterogeneous, especially in cities with high industrial level, large urban population and high innovation level.

Based on the above conclusions, this paper puts forward two policy recommendations: first, give full play to the advantages of the platform, promote the integration of production and marketing of enterprises, integrate the advantageous resources in the industrial internet, stimulate the market vitality, improve the liquidity of means of production and products, reduce the transaction cost of enterprises and the degree of information asymmetry, ease the redundancy of enterprise resources and improve the energy efficiency of all factors. Secondly, we will promote the construction of a digital economy and speed up the digital transformation of enterprises. We will strengthen the construction of digital infrastructure and provide policy and financial support for the digital transformation of enterprises. At the same time, we will firmly implement the policy of tax reduction and fee reduction to increase the enthusiasm of enterprises for digital transformation. Finally, create a good environment for innovation and entrepreneurship, increase the intensity of industrial technology, continuously promote the upgrading of urban industrial structure, promote the development of urban digital technology and green energy-saving technology, and promote the improvement of all-factor energy efficiency with the dual role of digital technology and energy-saving technology.

References

[1] M.Q.Fan,R.E.Ren, et al. An Empirical Study on the Impact of Technology Change, Factor Substitution and Trade on Energy Intensity.Economics(Quarterly), Vol. 9 (2010) No. 1, p.237-258.

[2] Y.Z.Cai,W.J.Ma. Impact of data elements on high-quality development and data flow constraints. Quantitative Economic and Technological Economic Research, Vol. 38 (2021) No. 3, p.64-83.

[3] X.Xiao,Y.D.Qi. Value dimension and theoretical logic of industry digital transformation. Reform, (2019) No. 8, p.61-70.

[4] L.Wang. Does the Digital Economy Increase Energy Consumption? —Analysis based on ICT application research. Urban and Environmental Research, (2021) No. 3, p.93-108.

[5] M.F.Wang,X.W.Zhang. Research on the mechanism of the influence of technological change on the production process in the digital economy era. Economist, (2020) No. 1, p.52-58.

[6] T.Zhao,Z.Zhang, et al. Digital economy, entrepreneurial activity and high-quality development-empirical evidence from China city. Management World, Vol. 36 (2020) No. 10, p.65-76.

[7] Y.W.Sun,Z.H.Hu. Digital Economy, Industrial Upgrading and Urban Environmental Quality Improvement. Statistics and Decision, Vol. 37 (2021) No. 23, p.91-95.

[8] X.W.Wang. Measurement of the Impact of Informatization on China's Industrial Energy Intensity. Statistics and Decision, Vol.34 (2018) No. 7, p.152-154.

[9] S.F.Zhang,X.H.Wei. Does Information and Communication Technology Reduce Enterprise Energy Consumption-Evidence from Survey Data of Manufacturing Enterprises in China. China Industrial Economy, (2019) No. 2, p.155-173.

[10] Z.G.Tu, L.K.Liu. Evaluation of China's Industrial Efficiency Considering Energy and Environmental Factors —— Provincial Data Analysis Based on SBM Model. Economic Review, (2011) No. 2, p.55-65.

[11] P.T.Zhang,X.W.Tu. Manufacturing Agglomeration, Technological Progress and Enterprise Total Factor Energy Efficiency. China Industrial Economy, (2022) No.7, p.103-121.

[12] S.H.Luo,W.Dong. Effects of Carbon Trading Policy on Provincial Total Factor Energy Efficiency. Economic Geography, Vol. 42 (2022) No. 7, p.53-61.

[13] T.Li,W.H.Sha. Research on the Impact of Digital Economy on Regional Total Factor Energy Efficiency: An Analysis of Intermediary Effect Based on Market Trade. Financial Theory and Practice, Vol.43 (2022) No. 3, p.120-127.

[14] D.Fan,T.T.Liu. Study on the impact mechanism and heterogeneity of low-carbon city pilot policies on total factor energy efficiency. Review of Industrial Economics, (2022) No.2, p.93-111.

[15] Y.S.Peng,F.H.Huang, et al. Research on the Path of internet plus Promoting the Innovation of Agricultural Products Circulation Mode. Logistics Engineering and Management, Vol.39 (2017) No.1,p. 97-99, 54.

[16] Y.Z.Cai,X.X.Niu. Measurement and structural analysis of China's digital economic added value scale. China Social Sciences, (2021) No. 11, p.4-30+204.

[17] Z.G.Cao. Research on a New Manufacturing Model to Promote High-quality Industrial Development in China under the Background of Digital Economy. Theoretical Discussion, (2018) No. 2, p.99-104.

[18] Y.Jiang. Intermediary effects and moderating effects in empirical studies of causal inference. China Industrial Economy, (2022) No. 5, p.100-120.

[19] L.H.Fu. An Empirical Study on the Relationship between China's Higher Industrial Structure and Economic Growth. Statistical Research, Vol.27 (2010) No. 8, p.79-81.

[20] S.D.Jiao,Q.B.Sun. Research on the Measurement of China's Digital Economy Development and Its Influencing Factors. Research World, (2021) No. 7, p.13-23.

[21] F.Deng,A.T.Yang, et al. R&D Subsidy and Technological Innovation of Digital Enterprises: Evidence from Digital Economy Industry. Industrial Economics Research, (2021) No. 4, p. 27-41.

[22] Y.X.L,X.M.Fang, et al. Digital Economy, Spatial Spillover and High-quality Development of Urban Economy. Economic Journal, Vol.38 (2021) No. 6, p.21-31.