Measurement of Digital Economy Development Level in Yangtze River Delta and Its Influence on Ecological Efficiency

Qing QIAO

College of City Construction, Jiangxi Normal University, Nanchang 330022, China

Abstract Based on the panel data of 41 cities in the Yangtze River Delta from 2007 to 2018, this paper empirically tests the impact of digital economy development on urban ecological efficiency in the Yangtze River Delta. The results show that the development level of digital economy in Yangtze River Delta urban agglomeration is fluctuating and rising; the development of digital economy has a significant positive role in promoting the improvement of urban ecological efficiency; there is significant regional heterogeneity in the promotion of ecological efficiency by digital economy, especially in central cities.

Key words Yangtze River Delta urban agglomeration, Digital economy, Ecological efficiency

1 Introduction

Ecological efficiency has become an important index to measure the green development in the process of changing the current economic development from the extensive mode of pursuing growth rate to the connotative mode of pursuing structural adjustment and environmental efficiency[1]. Related research mainly focuses on the macro research level such as industrial development and social effects, and the micro research level such as production factors and technological updating. However, there are few papers to analyze the synergistic relationship between the development of regional digital economy and the improvement of ecological efficiency. In view of this, this paper takes the development of digital economy in 41 cities in Yangtze River Delta from 2007 to 2018 as the research object, and studies its impact on urban ecological efficiency.

2 Measurement of digital economy development level in Yangtze River Delta

2.1 Index system Referring to the existing research and based on the availability and representativeness of data[2-4], this study intends to construct a comprehensive index system for measuring the development of digital economy from three levels: digital infrastructure, digital industry foundation and digital environment support (Table 1).

2.2 Development level of digital economy It can be seen from Fig. 1 that the overall development level of digital economy in the Yangtze River Delta is increasing year by year during the study period, from 0.198 in 2007 to 0.878 in 2018, with an average annual change rate of 16%, and the development level of digital economy is significantly improved.

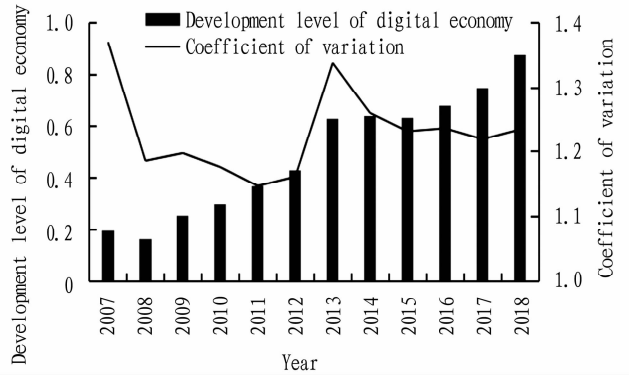

Fig. 1 Time series changes of digital economy development level in Yangtze River Delta urban agglomeration from 2007 to 2018

3 Influence of digital economy on ecological efficiency in Yangtze River Delta

3.1 Model setting In order to test the influence of urban digital economy development on ecological efficiency, this paper constructs the following panel model:

$$\ln EE_{it} = \beta_0 + \beta_1 \ln DE_{it} + \beta_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where i represents the city, t represents the year, EE_{it} represents the ecological efficiency of city i in period t, DE_{it} represents the digital economy development level of city i in period t, μ_i and λ_t are regional fixed effect and time fixed effect, respectively, and ε_{it} is random error term.

3.2 Variable definition

3.2.1 Explained variable. The explained variable is ecological efficiency (EE). Referring to the existing literature, this paper establishes the following ecological efficiency evaluation index system (Table 2), and uses the super-efficiency SBM model to measure the ecological efficiency of 41 cities in the Yangtze River Delta region from 2007 to 2018. With regard to capital elements, this paper uses perpetual inventory method to estimate the actual capital stock of each prefecture-level city, that is, the total investment in fixed assets in the initial year is divided by 10% as the base period capital stock, and the depreciation rate is 9.6%.

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Table 1 Evaluation index system of digital economy development

First-level index	Second-level index	Index description
Digital infrastructure	Internet penetration rate	Number of Internet broadband access users (1×10^4)
Digital industry foundation	Telephone penetration rate	Number of mobile phone users at the end of the year (1×10^4)
Digital environment support	Fixed telephone penetration rate	Number of fixed telephone users at the end of the year (1×10^4)
First-level index	Telecommunication business income	Telecommunication business income (1×10^8 yuan)
Digital infrastructure	Employees in digital industry	Number of employees in information transmission, computer service and software industry
Digital industry foundation	Economic base	Per capita GDP (yuan)
Development of science and technology		Proportion of tertiary industry in GDP (%)
	Second-level index	Expenditure on science and technology (1×10^4 yuan)
	Human resource support	Number of students in ordinary colleges and universities
		Expenditure on education (1×10^4 yuan)

Table 2 Ecological efficiency evaluation index system of Yangtze River Delta urban agglomeration

Index category	Dimension	Index selection	Unit
Input factor	Capital	Capital stock	1×10^8 yuan
	Labor	Number of employees at the end of the year	1×10^4
	Land	Built-up area	km^2
	Resources	Total annual electricity consumption	1×10^4 kW·h
		Total annual water supply	1×10^4 m^3
Output factor	Expected output	Regional GDP (at 2002 constant prices)	1×10^8 yuan
		Local fiscal revenue	1×10^8 yuan
Unexpected output	Discharge of industrial wastewater	1×10^4 t	
		Industrial waste emissions	t
		Industrial smoke (dust) emissions	t

3.2.2 Explanatory variable. The explanatory variable is the development level of digital economy (DE).

3.2.3 Control variable. Based on the existing literature, this paper selects the following control variables: economic development level (GDP); urban size (US); industrial structure (IS); scientific and technological level (TECH); level of opening to the outside world (FDI); government environmental regulation (ER).

3.3 Data sources The above data are all from *China Urban Statistical Yearbook*, *China Regional Economic Statistical Yearbook*, *China Environmental Statistical Yearbook*, *China Economic and Social Big Data Research Platform*, EPS database and statistical yearbooks of prefecture-level cities over the years. For some missing data, linear interpolation method is used to supplement them.

3.4 Empirical results and analysis

3.4.1 Baseline regression analysis. The regression results show that the coefficient of digital economy development level after cluster robustness adjustment is positive, and after adding control variables, the regression coefficient of digital economy development level rises from 0.261 3 to 0.273 3, significantly positive at the level of 1%, indicating that the development of digital economy is beneficial to the improvement of urban ecological efficiency. From the estimation results of control variables, the regression coefficients of economic development level, industrial structure and foreign investment are significantly positive.

Urban size, environmental regulation and ecological efficiency are significantly negative at the level of 1% and 5%, respectively. The regression coefficient of scientific and technological development is significantly negative, indicating that technological progress will inhibit the improvement of urban ecological efficiency in the Yangtze River Delta.

Table 3 Influence of digital economy on ecological efficiency (benchmark regression)

Variable	(1)	(2)
lnDE	0.261***(13.35)	0.273***(5.10)
lnGDP		0.268***(6.21)
lnUS		−0.443***(−10.42)
lnIS		0.617***(6.10)
lnER		−0.087**(−2.47)
lnFDI		0.041**(2.02)
lnTECH		−0.074**(−2.46)
Constant	0.365***(6.25)	−10.273***(−10.30)
Regional effect	Fixed	Fixed
Time effect	Fixed	Fixed
R^2	0.267	0.474
N	492	492

3.4.2 Regional heterogeneity analysis. In order to test the regional heterogeneity of influence, this paper breaks through the administrative boundary and divides 41 cities in the Yangtze River Delta into three regions (eastern, central and western) for grouping regression test (Table 4).

According to the regression results, the influence of digital economy development level on ecological efficiency in Yangtze River Delta region shows significant regional heterogeneity. The development level coefficients of digital economy in central and

western regions are significantly positive, while the estimation coefficient of digital economy development level in eastern region is positive but not significant.

Table 4 Heterogeneity test of influence of digital economy on ecological efficiency in three regional cities

Variable	(1) Eastern region lnEE	(2) Central region lnEE	(3) Western region lnEE
lnDE	0.034	0.285***	0.220*
	(0.45)	(2.69)	(1.93)
lnGDP	0.312***	0.235***	0.219**
	(4.92)	(3.25)	(2.28)
lnUS	−0.133**	−0.450***	−0.543***
	(−2.01)	(−5.03)	(−6.07)
lnIS	−0.035	0.757***	0.464**
	(−0.23)	(4.02)	(2.07)
lnER	−0.190***	−0.001	−0.101
	(−4.22)	(−0.02)	(−1.57)
lnFDI	0.046	−0.018	0.040
	(1.91)	(−0.33)	(0.94)
lnTECH	−0.336***	−0.111	−0.036
	(−4.10)	(−1.56)	(−0.55)
Constant	−5.92***	−10.258***	−10.098***
	(−3.70)	(−5.87)	(−4.72)
Regional effect	Fixed	Fixed	Fixed
Time effect	Fixed	Fixed	Fixed
R^2	0.456	0.382	0.355
N	180	168	144

3.4.3 Robustness test. (i) Replace digital economy variables. This paper further refers to Zhao Tao, Huang Huiqun and other scholars[5-6], and chooses to re-measure the development level of digital economy with the development level of Internet. According to the regression results, although there are slight differences in parameter estimates between the recalculated digital economy index and the original digital economy development level, the signs between parameter estimates have not changed, and they are all significant at the level of 1%. Therefore, the regression results can be considered to be robust.

(ii) Eliminate the influence of municipalities directly under the Central government. In the course of research, this paper finds that compared with the other 40 prefecture-level cities, Shanghai's digital economy development level and ecological efficiency are on the high side. Considering that if there are great values in the samples, the overall regression results may be biased. In order to make the samples more comparable and enhance the robustness of the test conclusions, Shanghai is excluded for test. After Shanghai is excluded, the conclusion that the development of digital economy in the Yangtze River Delta can improve ecological efficiency is still valid.

4 Conclusions

Based on the panel data of 41 cities in the Yangtze River Delta from 2007 to 2018, this paper measures the development level of digital economy in this region, and empirically tests the impact of digital economy development on urban ecological efficiency in the Yangtze River Delta. The specific conclusions are as follows:

(i) On the whole, the development level of digital economy in the Yangtze River Delta urban agglomeration showed an obvious upward trend from 2007 to 2018. (ii) The development of digital economy can obviously promote the improvement of urban ecological efficiency. Economic development level, industrial structure upgrading and foreign investment play a significant positive role in improving ecological efficiency, while urban scale expansion, environmental regulation and scientific and technological development cannot effectively improve urban ecological efficiency. (iii) There is significant regional heterogeneity in the impact of digital economy on ecological efficiency in the Yangtze River Delta, and its impact on ecological efficiency is the most significant in the central region, followed by the western region and it is the least significant in the eastern region.

5 Policy recommendations

Based on the above conclusions, this paper puts forward the following policy recommendations for the development of digital economy in the Yangtze River Delta and its impact on ecological efficiency: first, we should create new advantages in the digital economy and expand new space for economic development, accelerate the development of new generation digital technologies such as cloud computing, artificial intelligence and blockchain, consolidate the foundation of digital economy development in the Yangtze River Delta region, and promote high-quality economic development; second, we should break down the barriers to the development of digital economy between regions and attach importance to areas with weak foundation for the development of digital economy.

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