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A Study of the Impact of the Digital Economy on the Efficiency of Urban Green Economy—Based on the Yangtze River Delta City Cluster

LU Yang , MIN Tianwei
Jiangxi University of Finance and Economics, Nanchang, China

This paper adopts the non-expected output-super-efficiency SBM (Slacks-Based Model) model and principal component analysis to calculate the green economy efficiency and the digital economy level of 27 prefecture-level cities in China's Yangtze River Delta urban agglomeration between 2011 and 2019, respectively, and examines the impact of the digital economy on the green economy efficiency by using benchmark regression and mechanism analysis. The findings show that, first, the digital economy has a significant contribution to the green economic efficiency of cities, and this conclusion still holds after robustness tests such as replacing explanatory and interpreted variables and introducing province-fixed effects. Second, through the mechanism test, it is found that the digital economy can indirectly promote urban green economic efficiency through the positive mechanism effect of promoting industrial structure upgrading.

Keywords: digital economy, urban green economy efficiency, undesired output-super-efficiency SBM model

Introduction

Since the reform and opening up in 1978, China's economy has been growing at a rapid rate of 9.4% per year. By 2022, China's GDP will exceed 120 trillion yuan, and economic growth has achieved remarkable results. However, while the economy is growing at a rapid pace, the imbalance of industrial structure, inefficient input and output, and serious environmental pollution have increasingly become roadblocks to China's high-quality economic development. With the rapid development of the digital economy, the absolute amount of digital economic output and the relative amount of its share of GDP has been increasing, and it has been increasingly emphasized by all sectors of society to clarify whether the digital economy can become a new driving force for green development and promote the improvement of the efficiency of the green economy.

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LU Yang, Ph.D., lecturer, School of Economics, Jiangxi University of Finance and Economics, Nanchang, China.
MIN Tianwei, Master student, School of Economics, Jiangxi University of Finance and Economics, Nanchang, China.
Correspondence concerning this article should be addressed to LU Yang, School of Economics, Jiangxi University of Finance and Economics, Nanchang, China.

Literature Review

Most current scholars believe that the digital economy has a positive and positive impact on the improvement of green productivity. Among them, Zeng and Xiao (2022) measured the green economic efficiency of China's cities using the GML (Global Malmquist-Luenberger) index based on the panel data of 253 prefecture-level cities in China during 2011-2018 and empirically examined the role of digital finance in the promotion of green economic efficiency. Liu, Ma, and Xu (2022) empirically examined the role of the digital economy in green economic efficiency using provincial-level panel data in China during 2006-2019 as a sample. Zhu and Ma (2022) took the change of green total factor productivity affected by digital economic development as an entry point, constructed a theoretical model of the change of green total factor productivity under the role of digital economy through the analysis of innovation efficiency and factor mismatch, and revealed the internal mechanism of digital economic development to promote the improvement of green total factor productivity. Kong and Li (2022) comprehensively examined the effect of digital economic development on the improvement of green economic efficiency in China based on the panel data of 30 provinces in China from 2011-2019. Zhu and Li (2023) empirically examined the role of digital economy in the process of urban green development based on the panel data of 277 Chinese cities from 2011-2019 and explored the mediating mechanisms as well as spatial spillover effects.

Comprehensively, the above analysis shows that domestic and international research on digital economy and green economy efficiency has been very rich, but there are still some shortcomings: First, although the existing literature has more studies on provincial regions, there are fewer studies on the Yangtze River Delta (YRD) city cluster, which, as the largest city cluster in China in terms of population and GDP volume, has a digital economy scale that accounts for about 44% of the regional GDP, and about 30% of the total digital economy scale of the whole country. As the largest city cluster in China in terms of population and GDP, the scale of the digital economy accounts for about 44% of the regional GDP and about 30% of the total scale of the digital economy in China; it is necessary to study the mechanism of the influence of the digital economy on the efficiency of the green economy in the Yangtze River Delta, which can then provide experience for other city clusters. Secondly, in terms of variable measurement, the urban green economy efficiency is limited to the traditional DEA (Data Envelopment Analysis) model, which does not fully take into account the variable slack problem; therefore, this paper proposes to adopt the non-expected output-super-efficiency SBM index to measure the urban green economy efficiency, which effectively avoids the problem of slack variables and makes the empirical results more robust.

Theoretical Analysis of the Impact of the Digital Economy on the Efficiency of the Green Economy

This paper describes the intrinsic mechanism of the digital economy's impact on the efficiency of the green economy from the perspectives of direct and indirect roles and puts forward relevant research hypotheses.

Direct Mechanisms of the Digital Economy on the Efficiency of the Green Economy

First of all, the digital economy is extremely permeable, and digital infrastructure closely integrates all industries, breaking the spatial and geographical segregation and realizing the non-spatial agglomeration of industries through the establishment of virtual information platforms, through which people can access resources more efficiently and improve labor productivity. Secondly, at the same time, the digital economy also helps to promote the synergistic division of labor among industries, and through industrial association, industrial integration, and industrial innovation, it further eliminates high-pollution and high-input, high-emission industries and in turn promotes the development of the green economy. Finally, factors of production are the cornerstone of economic development, data as a new factor of production; there are network externalities that can empower the traditional economy, improve production efficiency, and then form economies of scale, thus promoting the development of the green economy. On this basis, the following conjecture can be made:

Hypothesis 1: The level of the digital economy has a direct linear effect on the efficiency of the green economy.

Indirect Mechanisms of the Digital Economy on the Efficiency of the Green Economy

In the third scientific and technological revolution, the digital economy is a new starting point, and its development mainly relies on the progress of information technology, which also promotes information technology, so that the output value of the information technology industry has been greatly enhanced. And the information technology industry mostly belongs to the category of service industry; therefore, the digital economy will promote the transformation of industry, so that the proportion of tertiary industry relatively increases, thus forming a driving force for the green economy. On this basis, the following conjecture is made:

Hypothesis 2: The level of the digital economy can affect the efficiency of the green economy through its impact on the structure of the industry and thus on the efficiency of the green economy.

Empirical Study on the Efficiency of Digital Economy on Green Economy in Yangtze River Delta City Cluster

Variable Measurement and Description

Explained variable: Green economy efficiency. Based on the comprehensive consideration of the factors of “energy consumption” and “environmental pollution”, we adopt the super-efficient SBM model with non-expected output to measure the green total factor productivity (GTFP) of the Yangtze River Delta city cluster concerning Yu and Wei (2021). The model can solve the variable relaxation problem in the measurement of green total factor productivity, thus ensuring the robustness of the results.

Among the input indicators are: (1) Input of labor force: The number of people employed in each city’s municipal jurisdiction represents the input of labor. (2) Capital inputs: The capital stock is measured using the perpetual inventory method. (3) Land input: The area of the built-up area of the municipal district is used to represent the input of land. (4) Energy input: This paper uses coal consumption to represent the energy input.

Output indicators include desired output and non-desired output, of which output indicators: (1) Desired output: Output indicators are expressed in terms of the real GDP of the cities, and 2006 is chosen as the base period to calculate the GDP deflator according to the GDP index of the provinces in which the cities are located in the previous years, and then deflated by the multi-year nominal GDP of the cities, excluding the price factor. (2) Non-expected outputs: According to Tu (2008), this paper takes the urban industrial SO2 emissions, industrial wastewater emissions, and six industrial soot emissions as non-expected outputs.

Explanatory variables: Digital economy. In terms of digital economy index measurement, there is currently some divergence in the research methods used by scholars. Compared with the provincial level, the urban municipal level is more constrained in terms of data availability. Based on the data availability at the city level and referring to Zhao et al. (2020), this paper takes the development of the Internet as the core of measurement and adds the indicator of digital transactions to measure the level of digital economy development with the dimensions of Internet development and digital financial inclusion. The Internet development measurement indicators are shown in Table 1. Data for all four indicators can be found in the China Urban Statistical Yearbook. For digital financial development, the China Digital Financial Inclusion Index is used, which is jointly compiled by the Digital Finance Research Center of Peking University and Ant Gold Service Group. The comprehensive development index of the digital economy obtained by standardizing and downscaling the data of the above five indicators through principal component analysis is denoted as DEI (Digital Economic Index).

Table 1

Digital Economy Measurement System

Composite indicators	Primary indicators	Secondary indicators	Type of indicator
Level of the digital economy	Internet development	Number of Internet broadband subscribers	Positive
		Employees in the computer services and software industry as a percentage of employees in urban units	Positive
		Total telecommunication services per capita	Positive
		Number of cell phone subscribers	Positive
	Digital financial inclusion	Digital Inclusive Finance in China Index	Positive

Mechanism variables. Concerning Fu (2010), the article constructs the mechanism variables of industrial structure advancedization. Industrial structure advanced, that is, along with the development of sustained economic growth, the industrial structure is also followed by a regular process of change, mainly reflected in the proportion of the three industries along the primary, secondary, and tertiary industries climbed in turn. The formula is as follows:

$$W = \sum_{k=1}^{3} \sum_{j=1}^{k} \theta_j \quad (j = 1, 2, 3) \tag{1}$$

where θ_j denotes the value of the inverse cosine function of j's industry's share of GDP.

Relevant control variables. Referring to Lin and Tan (2019), the following control variables are selected: the level of urban economic development (lnpgdp): The natural logarithm of the real GDP per capita is selected for measurement; the degree of government intervention (lngov): The degree of government intervention has a significant impact on the efficiency of the green economy, which is expressed as the logarithm of the ratio of the share of fiscal expenditure to the ratio of the GDP of the region; the degree of foreign direct investment (lnfdi): Foreign investment has the dual possibility of “technology diffusion effect, etc.”, which promotes the efficiency of the green economy, but also leads to the assumption of “pollution paradise”, which curbs the improvement of the efficiency of the green economy, expressed as the logarithm of the ratio of the amount of actual foreign investment to the GDP plus one. It is expressed as the logarithm of the ratio of actual foreign investment and regional GDP plus one; environmental regulation (lnenvre): That is measured by the logarithm of the comprehensive utilization rate of industrial solid waste plus one; and the level of technological innovation (lntec): That is measured by the logarithm of the ratio of local financial expenditures on science and technology to the regional GDP plus one.

Model Setup

Baseline model. To test the direct impact of the digital economy on the efficiency of the green economy, this paper first constructs the following benchmark model:

$$GTFP_{i,t} = \alpha_0 + \alpha_1 DEI_{i,t} + \alpha_c X_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \tag{2}$$

In Equation (2), $GTFP_{i,t}$ is the green economic efficiency of the city i in a year t, $DEI_{i,t}$ is the level of digital economic development of the city in a year t, the vector is a series of control variables, μ_i is the individual fixed effect, δ_t is the time fixed effect, and is the random disturbance term. To be as robust as possible, this paper adopts the individual and time two-way fixed effects model for robustness testing.

Mechanism analysis model. In addition to the direct mechanism reflected in Equation (2), to further examine the indirect mechanism of the digital economy's effect on the city's green economy efficiency enhancement, this paper will empirically test whether the industrial structure exerts a mechanism effect by referring to the research concept of Jiang (2022). The model is as follows:

$$\ln w_{i,t} = \alpha_{01} + \alpha_{11} DEI_{i,t} + \alpha_{c1} X_{i1,t} + \mu_{i1} + \delta_{t1} + \varepsilon_{i1,t} \tag{3}$$

In Equation (3), $\ln w_{i,t}$ is the industrial structure advanced index of the city in year t, $DEI_{i,t}$ is the level of digital economy development of the city i in a year t, the vector is a series of control variables, μ_{i1} is the fixed effect of prefecture-level cities, δ_{t1} is the fixed effect in time, and is the random disturbance term.

Data Sources

This paper studies 27 prefecture-level cities in China's Yangtze River Delta from 2012 to 2020, forming a balanced panel of observations for 243 samples, and using the interpolation method to supplement the missing data for individual cities. The data in this paper come from the China Urban Statistical Yearbook, municipal statistical yearbooks, the EPS (Economy Prediction System) database, and the Peking University Financial Inclusion Index.

An Empirical Test of the Digital Economy on Green Economy Efficiency in the Yangtze River Delta City Cluster

Basic regression results. To examine the direct mechanism of the digital economy's effect on the efficiency improvement of the green economy, this study adds the control variables to the baseline regression one by one to observe them, avoiding the effect caused by omitted variables. The regression results are shown in Table 2.

Table 2

Basic Regression Results

	(1)	(2)
	GTFP1	GTFP1
DEI1	0.68***	0.44***
lnpgdp		37,586.84***
lnurban		-7,929.64
lngov		203,098.20**
lntec		-476,855.66
lnenvre		-56,266.66
lnfdi		-145,978.42
Constant	993,902.89***	844,471.24***

Notes. ***, **, * denote 1%, 5%, and 10% significance levels, respectively.

Column (1) is the regression result without adding any control variables, and the coefficient of the digital economy level is 0.68, which is significant at the 1% level, indicating that the digital economy positively promotes high-quality development and is very significant. Meanwhile, after gradually adding control variables such as the level of urban economic development, urbanization rate, the degree of government intervention, the level of scientific and technological innovation, foreign direct investment, and environmental regulation, it can be found that the regression coefficient of the level of the digital economy in Column (2) is always greater than zero, and it is significant at the level of 1%, which further suggests that the digital economy significantly improves the efficiency of the urban green economy. From the benchmark regression results presented in Column (2), for every unit increase in the degree of digital economy, the city's green economic efficiency will increase by 0.44 units, which indicates that in the benchmark model, the direct promotion of the digital economy to the city's green economic efficiency can be confirmed, and the results remain robust in the case of controllable disturbances in other elements of the city's economy, so Hypothesis 1 of the studies passes the test. The coefficients and significance regarding the control variables indicate that the level of urban economic development and the increase in the level of government intervention also have a contributing effect on urban green economic efficiency. Overall, the results of the baseline regression for the core explanatory variables and some of the control variables are as expected.

Robustness test. Replacement of core explanatory variables: To test the robustness of the baseline regression results, the section starts by replacing the core explanatory variables. The digital economy 2 (DEI2) measured according to the entropy weight method replaces the digital economy 1 (DEI1) measured using principal component analysis, and the DEI2 calculated by the entropy weight method can also better describe the degree of development of the digital economy in each city, so this paper uses the DEI2 to replace the original core explanatory variable—the level of the digital economy (DEI1) to do the regression analysis. Therefore, this paper uses DEI2 instead of the original core explanatory variable—digital economy level (DEI1) to do regression analysis, and the regression results are shown in Table 3.

Table 3

Results of Replacement Core Explanatory Variable Tests

	(1)	(2)
	GTFP1	GTFP1
DEI2	0.22***	0.11**
lnpgdp		0.03**
lnurban		0.02
lngov		0.24**
lntec		0.24
lnenvre		-0.04
lnfdi		-0.11
Constant	0.97***	0.73***

Notes. ***, **, * denote 1%, 5%, and 10% significance levels, respectively.

Column (1) is the regression result without adding any control variables, the regression coefficient of the digital economy level reaches 0.22, and the significance level reaches 1%, which indicates that the digital economy can promote the efficiency of urban green economy, and it is very significant. Meanwhile, after gradually adding one control variable such as the level of urban economic development and urbanization rate, the degree of government intervention, the level of scientific and technological innovation, environmental regulation, and foreign direct investment, it can be found that the regression coefficients of DEI2 in Column (2) are still greater than zero, and all of them are significant at a high level, which further indicates that DEI2 promotes the efficiency of the urban green economy significantly. From the regression results in Column (2), it can be seen that after replacing the core explanatory variables, the digital economy is still more than zero, and all of them are significant at a high level. The horizontal regression coefficients are all significantly positive, and their results match those of the benchmark regression, thus showing the robustness of the previous findings.

Mechanism Analysis

The empirical results of the previous benchmark regression have shown that the digital economy has an obvious promotion effect on the efficiency of the urban green economy; in order to explore its influence mechanism in-depth, this paper takes the advanced industrial structure as a mechanism variable for research, and uses the mechanism effect model to carry out further empirical analysis. The regression results are shown in Table 4.

Table 4

Mechanistic Effects of Industrial Advancement

	(1)	(2)
	lnw	lnw
DEI1	0.95***	0.44***
lnpgdp		15,105.35***
lnurban		122,136.23***
lngov		-141,957.36***
lntec		184,566.71
lnenvre		17,217.59
lnfdi		-374,241.21***
Constant	1,894,555.98***	1,176,560.41***

Notes. ***, **, * denote 1%, 5%, and 10% significance levels, respectively.

Column (2) regresses the core explanation of digital economy (DEI1) on the mechanism variable industrial structure advanced (lnw), and the results show that the regression coefficient is greater than zero and significant at the 1% level, which indicates that the digital economy can have a facilitating effect on industrial structure advanced. Since the digital economy can significantly promote the improvement of urban green economic efficiency, and the industrial structure advancedization shows the improvement of green development efficiency at the national level (Zhao et al., 2016), which implies that the mechanism effect exists, the digital economy can improve the efficiency of green development through the improving the industrial structure advanced and thus promoting the efficiency of urban green economy, that is, proving that Hypothesis 2 of this paper is valid.

Conclusions and Policy Recommendations

Conclusions

This paper analyzes the green value that the digital economy brings to the economy and society and measures the green economy efficiency and digital economy level of 27 prefecture-level cities in China’s Yangtze River Delta urban agglomeration between 2011 and 2019 by applying the non-expected output super-efficiency SBM model and principal component analysis. Based on this, the following conclusions are drawn through benchmark regression and mechanism analysis as well as robustness test: First, the digital economy can significantly improve the efficiency of the green economy, a conclusion that still holds after robustness tests such as replacing the measurement methods of explanatory and interpreted variables and introducing province fixed effects. Second, the digital economy can indirectly promote the city through promoting the positive mechanism effect of industrial structure upgrading the efficiency of the city's green economy, which shows that the industrial structure has changed under the digital economy, and it can be seen that the supply-side structural reform is an important way to promote the city to optimize the efficiency of the green economy.

Policy Recommendations

Combined with the above conclusions, this paper gives two policy-related suggestions: first, accelerate the transformation of industrial structure, do a good job of supply-side structural reform tasks, and make up for China's shortcomings in the level of technological innovation and digital technology. Secondly, the Yangtze River Delta city cluster as a whole has a high level of digital economy development, but there is still a big gap between the development levels of different cities, and the 18 regions that are relatively backward in development should learn from and integrate a set of digital economy development models suitable for themselves, and maximize the use of the economies of scale of the digital economy to the benefit of urban green development.

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