Analysis of the spatial effect of digitization on economic green growth

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Abstract. The entropy weight method is used to quantify the amount of provincial digitization based on China's provincial panel data from 2014 to 2019. Finally, the spatial Durbin model is used to assess empirically the influence of digitalization on economic green development and its spatial spillover effect. The SBM model is utilized to measure the efficiency of economic green growth. It has been shown that there is a spatial relationship between China's provinces' economic green growth and digital development. Every 10% increase in the province's digital development level will, assuming other influencing factors stay constant, not only raise the average level of economic green growth in the province by 9.524%, but will also indirectly raise the level of economic green growth in neighboring provinces by 8.818%. Based on the empirical findings, this study suggests optimizing the digital industrial structure and fostering the free flow of data elements in order to support China's economy's green development.

Keywords: Digitalization, Economic green development, Durbin spatial model, Effect of spatial spillover

1 INTRODUCTION AND LITERATURE REVIEW

China's digital technology has advanced quickly in recent years due to the intensifying new wave of scientific and technological revolution and industrial transformation. All regions are supporting this digital transformation in order to attain high-quality growth at the digital level. The "Recommendations of the Central Committee of the Communist Party of China on the Formulation of the 14 th Five-Year Plan for National Economic and Social Development and the Vision for the Year 2035," which was adopted by the 19th Central Committee of the Communist Party of China during its Fifth Plenary Session, emphasized the significance of speeding up digital development. In 2023, the two sessions also emphasized the significance of digitization in assisting regional economic development from point to area. The advancement of digitization has produced enormous economic gains. How to take advantage of digitalization's opportunities to foster new business models and industrial growth? This can be achieved by investigating high-quality economic growth, resource conservation and utilization, and green economic development with minimal resource use and environmental protection. This is

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crucial from a practical standpoint to support the green transformation of society and the economy.

Academic research on the effects of digitalization on economic green growth is now available. Xu Yubing et al. (2024)[1] conducted study using panel models and panel data of 96 cities in China's Yangtze River Economic Belt from 2011 to 2020. The study came to the conclusion that by speeding up factor flow, digital transformation can indirectly support inclusive green growth. According to Liu Jie et al. (2023)[2], when the digital economy expands, it has a U-shaped effect on the expansion of the green economy and, at a certain point, it can stimulate that growth. Shang Juan and colleagues (2023)[3] proposed the use of instrumental variables, Tobit regression, phased regression, and other robustness tests and concluded that the digital economy may greatly advance the growth of the green economy.

To put it succinctly, several academics have examined the relationship between digitalization and green economic growth. However, because definitions and assessment metrics for these concepts vary, research findings may vary. Conversely, there aren't many in-depth research on how digitization affects economic green growth in different geographic locations. In order to investigate the impact of China's digital development on economic green growth and spatial spillover effects, this paper will fully account for the spatial effect factors that have not been extensively explored in prior research. It will do this by using spatial panel data to empirically test whether the impact of digitization on economic green growth has a spatial correlation.

2 RESEARCH DESIGN

2.1 Model setting

Model selection and building

The standard panel regression model that follows is initially built in this paper:

$$Egg_{it} = \alpha_0 + \alpha_1 Dig_{it} + \alpha_2 CV_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

In Equation (1), $\boldsymbol{Egg_{it}}$ is the level of economic green growth explained by the variable, $\boldsymbol{Dig_{it}}$ is the primary determinant of digital level, and $\mathbf{CV_{it}}$ is an array of control factors. $\boldsymbol{\mu_i}$ and $\boldsymbol{\gamma_t}$ are Time- and individual-specific fixed effects, respectively, and $\boldsymbol{\varepsilon_{it}}$ is an arbitrary incorrect term.

Prior research has demonstrated a high spatial link between the degree of digitalization. As a result, there will be some bias in the measurement results if the spatial heterogeneity of the degree of digitization and economic green growth is ignored. As a result, the following spatial econometric model is selected for analysis in this work.

$$Egg_{it} = \alpha_0 + \rho W Egg_{it} + \beta_0 Dig_{it} + \beta_1 CV_{it} + \theta_0 W Dig_{it} + \theta_1 W CV_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (2)$$

In Equation (2), $\boldsymbol{\rho}$ is the spatial autoregressive coefficient of the explained variable, $\boldsymbol{\beta_0}$ is the explanatory variable's correlation, $\boldsymbol{\beta_1}$ is the control variable's coefficient, $\boldsymbol{\theta_0}$

is the explanatory variable's coefficient of the spatial interaction term, $\boldsymbol{\theta_1}$ is the control variable's spatial interaction term's coefficient, and $\mathbf{W}$ is the matrix of spatial weights.

The choice of the spatial weight matrix

Five spatial weight matrices—the adjacency weight matrix, the inverse distance matrix, the inverse distance square weight matrix, the economic distance matrix, and the economic geography nested matrix—are chosen for analysis and research in this paper in addition to the research problems and requirements of the robust test. The parameter of the economic nested matrix is 0.5.

2.2 Index selection and data description

Explained variable

This paper measures the efficiency of economic green growth using the SBM efficiency measurement model of undesirable output, referring to the methodology of Zhao et al. (2016)[4]. The following are the particular forms:

$$min\rho^* = \frac{1-\frac{1}{n}\sum_{i=1}^{n} s_i^- / x_{i0}}{1+\frac{1}{u+v}\left(\sum_{j=1}^{n} s_j^g / y_{j0}^g + \sum_{j=1}^{b} s_j^b / y_{j0}^b\right)} \tag{3}$$

$$s.t.\, x_0 = X\lambda + s^-, y_0^g = Y^g\lambda - s^g, y_0^b = Y^b\lambda + s^b, \lambda, s^g, s^b, s^- \geq 0$$

In the above formula, only when $\boldsymbol{\rho}^* = \mathbf{1}$, the evaluation unit is efficient. The average expansible ratio and average reducible ratio of the assessed unit's actual input and output in relation to the production technology frontier are represented by the numerator and denominator of $\boldsymbol{\rho}^*$**.**

Both input and output variables are considered in the assessment of the effectiveness of regional economic green development. Capital, labor, and energy are examples of input variables; expected and undesirable output are examples of output variables.[5] The number of employees at the end of the year is used in this study to represent labor input. Regarding capital stock, each region's capital stock data are transformed into a 2014 base period and extended to 2019. Standard coal is the primary energy usage when it comes to energy intake. GDP is the anticipated output, with 2014 serving as the base year. In addition, three types of energy—coal, oil, and natural gas—are chosen for classified energy in this article, with carbon dioxide and the industrial "three wastes" serving as symbols for undesirable output.

Explanatory variables

Regarding the digitization level measurement index, the four parameters of digital infrastructure, digital industrialization, industrial digitization, and digital innovation ability are measured using the entropy weight approach, as per Zhao Tao et al. (2020)[6]'s practice (see **Table 1**).

Table 1. Digital level measurement index system

first grade indexes	second index	Indicator description	international unit
digital infrastructure	internet penetration	Ports available for broadband Internet connectivity	Ten thousand
		Number of Internet broadband access users	Ten thousand households
		Number of Internet Domain Names	Ten thousand
	The popularity of mobile phones	Mobile phone base station density	One / km^2
		mobile subscription	One / 100 people
	Breadth of information transmission	Length of long-distance optical cable per unit area	One kilometer/ km^2
digital industrialization	software and information technology services	The proportion of software business income in GDP	%
		Number of employees in information transmission, software and information technology services	Ten thousand people
	The development level of electronic information manufacturing industry	The proportion of information technology service income in GDP	%
		The proportion of total telecommunication business in GDP	Ten thousand people
		Total telecommunications business per capita	One RMB / person
	The development level of post and telecommunication industry	Total postal business per capita	One RMB / person
		express quantity	Ten thousand pieces
		Enterprise e-commerce transaction volume	One hundred million yuan
industrial digitalization	The degree of digital development of enterprises	Proportion of enterprises in e-commerce transaction activities	%
		Number of computers used per 100 people in enterprises	One person
		Number of websites per 100 enterprises	one
	digital inclusive finance	digital inclusive financial index	/
Digital innovation capability	Research and experimental development level	R&D employees in industrial companies larger than the designated size are comparable to full-time employees.	person / year

	R&D spending by industrial companies larger than the target size	Ten thousand yuan
	Number of industrial businesses' R&D initiatives (projects) that exceed the designated size	feature
technological innovation capability	Total technical contract turnover	Ten thousand yuan
	Number of patent application authorizations	piece

Control variable

This document chooses the degree of development of the economy(expressed as GDP / total population at the end of the year), industrial structure (expressed as the added value of the second and third industries / GDP), government regulation (expressed as general public budget expenditure / GDP), and population density (expressed as permanent population at the end of the year / total population) as control variables in light of the relationship between the degree of digitization and the economy's green growth as well as other exogenous variables that may affect the green growth of the economy. In addition, the degree of economic progress is treated logarithmically in this work.

Sources of Data and Explanations

The research sample for this study involves panel data from 30 Chinese provinces (cities / districts), excluding Tibet, Hong Kong, Macao, and Taiwan. Numerous reputable statistical yearbooks, such as national and provincial statistical yearbooks, environmental status bulletins, and certain professional statistical yearbooks, are used to gather and compute the data.

3 ANALYSES AND EMPIRICAL FINDINGS

3.1 Test for spatial autocorrelation

The global Moran index

This study tests the spatial dependence of data variables using the global Moran's I index. The process used to calculate Moran's I index:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i-\bar{x})(x_j-\bar{x})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{4}$$

In formula (8), n = 30, $\mathbf{x_i}$ and $\mathbf{x_j}$ represent the sample values of space **i** and space **j** respectively, $\bar{\mathbf{x}}$ is the mean value of variable data **x**, $\mathbf{S^2}$ is the variance of **x**, and $\mathbf{W_{ij}}$ is the spatial weight matrix.[7]

Table 2 presents the findings. Every Chinese province has a strong positive autocorrelation between its digital level and economic green growth, as demonstrated by the fact that between 2014 and 2019, Moran's I of the digital level and the level of economic green growth are significantly positive at least at the 5% level.

Table 2. Moran 's I index of China 's digital level and economic green growth from 2014 to 2019

particular year	digitalization level	The level of economic green growth
2014	0.067**	0.156***
2015	0.071**	0.160***
2016	0.044**	0.169***
2017	0.062**	0.174***
2018	0.058**	0.175***
2019	0.068**	0.190***

Note : ***, **, *are significant at the levels of 1 %, 5 % and 10 %, respectively.

Moran scatter plot

In addition, a local Moran scatter plot is presented in this work (**Fig 1-Fig 4**), which solely presents test findings from 2014 and 2019. The majority of the provinces are dispersed in the first and third quadrants of the plot, which displays the spatial characteristics of high-high aggregation and low-low aggregation. The local Moran index of digitization level and economic green growth is positive.

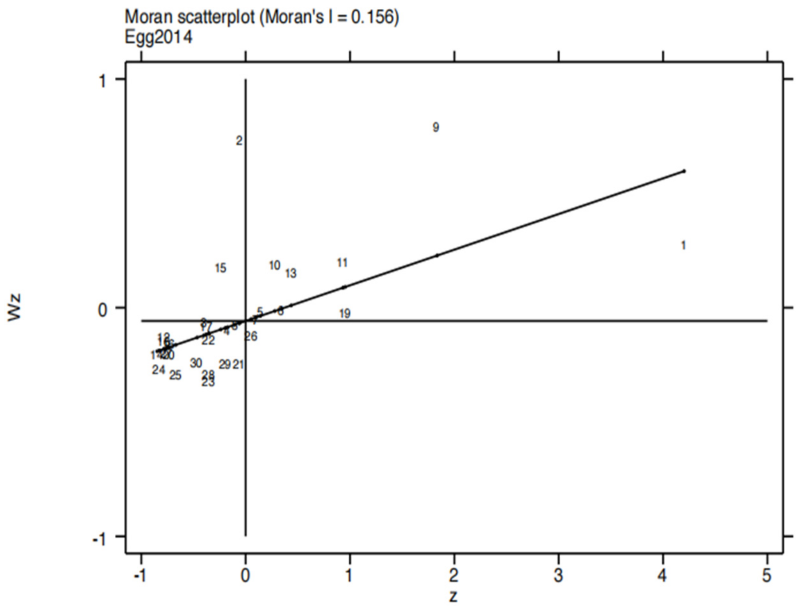

Fig. 1. Moran 's I index scatter plot of Egg in 2014

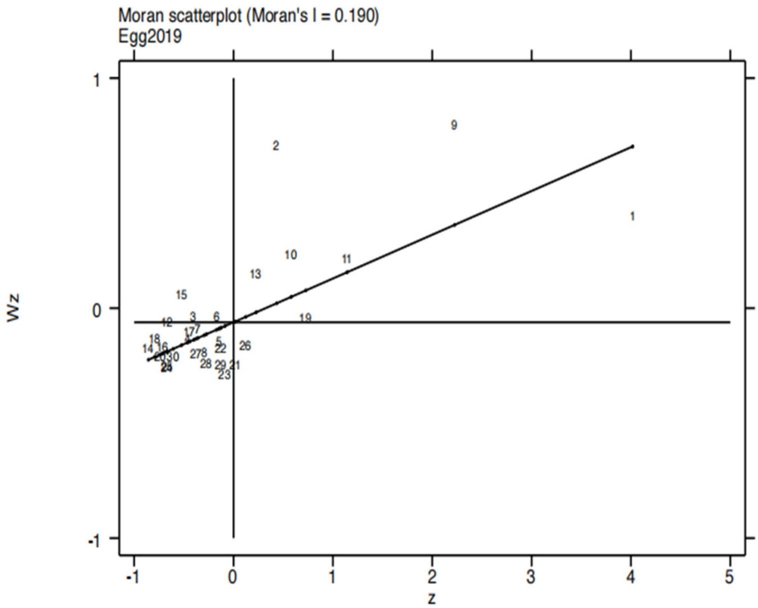

Fig. 2. Moran 's I index scatter plot of Egg in 2019

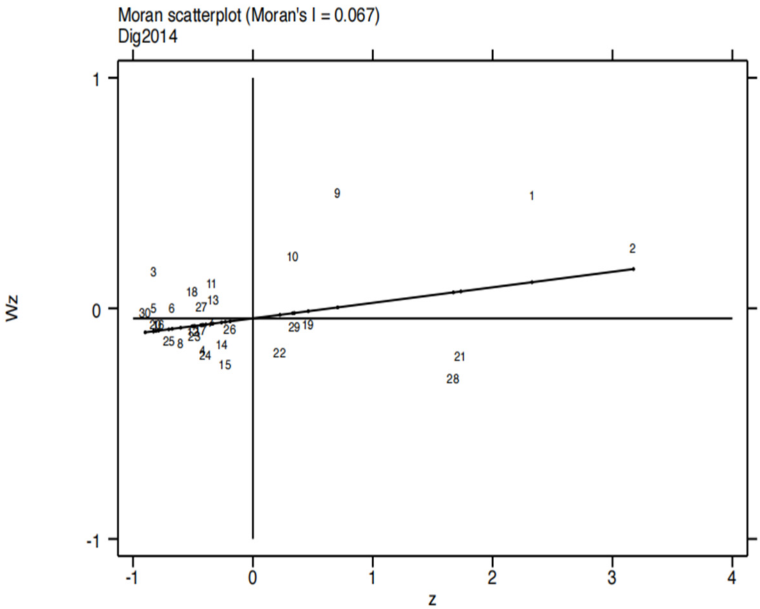

Fig. 3. Moran 's I index scatter plot of Dig in 2014

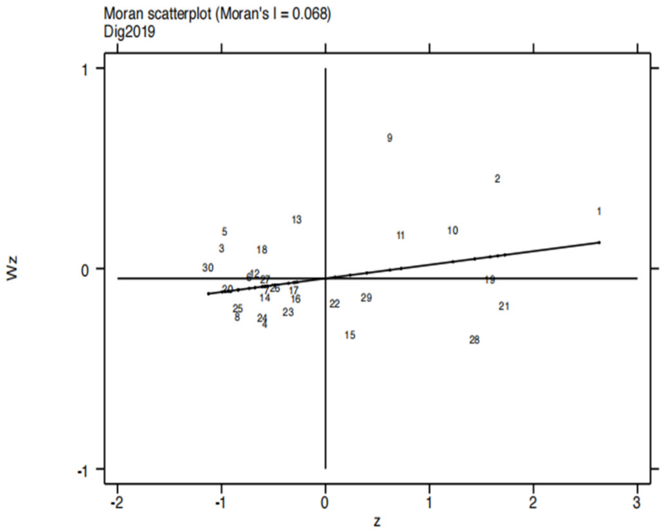

Fig. 4. Moran 's I index scatter plot of Dig in 2019

3.2 Diagnosis and identification of spatial econometric model

Since SDM cannot be broken down into SLM and SEM, the LR and Wald statistics in this work pass the 5% significance test, suggesting that the spatial Durbin model should be used for analysis in this work. Furthermore, the fixed effect model ought to be chosen since the Husman test rejects the null hypothesis of random effects at the 1% significant level. In conclusion, the Durbin model with a fixed effect spatial panel is more suited for this investigation.

3.3 Analysis of spatial measurement results

The spatial autoregressive model (SAR), spatial error model (SEM), and spatial Durbin model (SDM) are regressed under the chosen inverse distance square matrix, spatial adjacency matrix, and economic geography nested matrix, respectively.

The major explanatory variable digitization level (Dig) in **Table 3** under the three spatial weight matrices and the spatial Durbin model has a considerably positive coefficient, indicating that China's economic green development level will rise as digitalization continues to advance.

Table 3. Parameter estimation results of spatial panel Dubin model

	Anti-distance square matrix			spatial adjacent matrix			Economic geography nested matrix		
	SAR	SEM	SDM	SAR	SEM	SDM	SAR	SEM	SDM
Main									
Dig	0.9206*	0.9966*	0.9961*	0.9130*	0.998	0.835	0.879	0.9550*	0.9511*

	** (6.27)	** (6.47)	** (6.39)	** (6.20)	7*** (6.78)	8*** (5.37)	9*** (5.97)	** (6.22)	** (5.25)
control variable	YES	YES	YES	YES	YES	YES	YES	YES	YES
rho	-0.1179 (-1.05)		-0.2803** (-2.21)	-0.0495 (-0.51)		-0.2024* (-1.72)	-0.3014 (-1.38)		-0.4462* (-1.71)
lambda		-0.2588** (-1.98)			-0.3065** (-2.46)			-0.4611* (-1.75)	
σ^2	0.0005*** (9.48)	0.0005*** (9.44)	0.0005*** (9.43)	0.0005*** (9.46)	0.0005*** (9.38)	0.0005*** (9.42)	0.0005*** (9.46)	0.0005*** (9.39)	0.0005*** (9.38)
WxDig			1.3293*** (3.41)			0.5008* (1.70)			1.7395* (1.90)
N	180	180	180	180	180	180	180	180	180

3.4 Decomposition of spatial spillover effect

This paper splits the spatial spillover effects into direct effects and indirect effects, as indicated in **Table 4**, to more intuitively understand the influence of explanatory variables and control variables on the explained variables. Under the three weight matrices, the digital development level (Dig) has a positive direct, indirect, and total influence. Simultaneously, the indirect impact of digital development on economic green growth has a regression coefficient of 0.8818 under the inverse distance square matrix, and it is significant at the 1% level. This indicates that for every 10% increase in the province's digital development level, the average economic green growth level will rise by 9.524%, assuming other influencing factors stay the same. Additionally, the province will indirectly contribute to an 8.818 % increase in the economic green growth levels of neighboring provinces.

Table 4. Spatial effect decomposition results

	Anti-distance square matrix			spatial adjacent matrix			Economic geography nested matrix		
	direct effect	indirect effect	gross effect	direct effect	indirect effect	gross effect	direct effect	indirect effect	gross effect

Main									
Dig	0.9524*** (6.04)	0.8818*** (2.97)	1.8341*** (5.20)	0.8268*** (5.18)	0.2918* (1.23)	1.1186*** (3.86)	0.9172*** (5.23)	0.9844* (1.65)	1.9017*** (2.80)
control variable	YES	YES	YES	YES	YES	YES	YES	YES	YES

3.5 Robust test

Explanatory variables and the spatial weight matrix are swapped out in order to perform the robustness test. Use an inverse distance matrix in place of the original matrix. The degree of digital development is then measured using the global principal component method to replace the primary explanatory variables, taking into account the five dimensions of Internet penetration rate, mobile phone penetration rate, number of Internet employees, telecom industry development, and digital financial development. **Table 5** displays the regression results, which are strong.

Table 5. Robust test results

	Substitute space matrix	Substitution space matrix and substitution variables
Dig	1.0499*** (6.51)	1.3830*** (6.36.)
WxDig	3.2570*** (3.15)	1.5633* (3.82)
rho	-1.0580*** (-3.23)	-0.5799*** (-2.16)
σ2	0.0005*** (9.50)	0.0005*** (9.32)
control variable	YES	YES
Individual and time fixed effects	YES	YES
N	180	180

4 CONCLUSIONS AND POLICY RECOMMENDATIONS

Based on the four dimensions of digital infrastructure, industrial digitization, industrial digitization, and digital innovation ability, this study measures the digitization level using the entropy weight approach. The panel data of 30 provinces in China from 2014 to 2019 is used in the analysis. Simultaneously, economic green development efficiency is measured using the SBM model. This research ultimately chooses the inverse distance square matrix, spatial adjacency matrix, and economic geography nested matrix to create a spatial Durbin model in order to investigate the influence of digital development on economic green development and spatial spillover effect. The main conclusions are as follows: The degree of digital development and economic green growth have a positive spatial autocorrelation, and digitization has a positive spatial spillover effect on regional economic green development, per the three matrices. Even after the robust test of substitution variables and matrices, the conclusion is still true.

The following policy recommendations are provided by this article in light of the aforementioned conclusions:

First, assist in the growth of the green economy and optimize the digital industrial structure. It is imperative that we proactively transform the conventional industrial production structure, conduct thorough research, and devise strategies to encourage the superior growth of the digital sector, ultimately establishing a globally competitive digital industry cluster. Give full play to the role of digitization in promoting circular economy.[8]

Second, the integration of digital and green technologies must be encouraged first, followed by cross-sectoral and cross-industry collaboration, knowledge sharing, technology transfer, and the coordinated development of the digital and green transformation, in order to achieve green economic growth.

Third, in order to support digital development, we should fully utilize the potential of data elements, rely on the relative advantages of regional resources, modify measures to local conditions, and put secret policies into place. At the same time, in order to achieve coordinated regional growth and reduce the digital divide in different regions, we should encourage the free flow of information components among provinces.

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