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Research on the Impact of Industrial Agglomeration on Green Development in the Yangtze River Economic Belt—Regulation Based on Digital Transformation Role

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Abstract: *Under the new development pattern, it is important to use the digital economy as the driving engine to promote the green development path of industrial agglomerations along the Yangtze River Economic Belt that balances environmental and economic benefits. This study takes 11 provinces and cities along the Yangtze River Economic Belt from 2011 to 2020 as samples, and analyzes the specific effects and internal relationship between manufacturing agglomeration and digital transformation on green development in the Yangtze River Economic Belt through theoretical analysis, construction of a scientific evaluation index system to measure the development status, and establishment of an empirical model. Finally, we conclude that the relationship between industrial agglomeration and green development is inverted U-shaped, digital transformation can positively strengthen this inverted U-shaped relationship, and there is regional heterogeneity in both, and finally put forward the countermeasure suggestions of this paper in combination with the real problems.*

Keywords: *Industrial Agglomeration; Digital Transformation; Green Development; Yangtze River Economic Belt*

1. Introduction

1.1 Research Background

Accelerate the promotion of green low-carbon sustainable development, promote the comprehensive green transformation of economic and social development, low-carbon economic development is related to the sustainable development of the Chinese nation and the building of a community of human destiny, in this context how to take into account both environmental and economic benefits, and coordinate the dual goals of green transformation and economic growth has become an important issue related to the healthy development of China's economy. Digital transformation can be used as a new power engine to empower China's green development, and the manufacturing industry, as the most productive and dynamic national economy with the most obvious characteristics of agglomeration, is the main battlefield of the real economy and digital economy. It is urgent for the manufacturing industry to promote high-quality development by the path of "double-wheel drive" of digitalization and greening, and to give full play to the positive externalities of manufacturing agglomeration to promote regional green development by taking digital transformation as an opportunity.

As an inland economic belt covering nine provinces and two cities, traversing east and west, radiating north and south, and with manufacturing as its traditional advantage, the Yangtze River Economic Belt is one of the "Three Strategies" implemented by the central government. Its economic and ecological development can play a great role as a model for other industrial agglomerations. The Yangtze River Economic Zone will account for 46.9% of the total economic development of the country in 2021, and its energy consumption and carbon emissions are large in base and still in the rising range, and its digital green transformation has great potential. Therefore, This study takes the Yangtze River Economic Zone as a sample and focuses on the relationship between manufacturing agglomeration, digital transformation and green development in the low-carbon context and its influence mechanism.

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1.2 Research significance

This paper establishes an analytical framework for the impact of industrial agglomeration and digital transformation on green development in the Yangtze River Economic Belt. Firstly, it summarizes and summarizes the relevant literature at home and abroad, and establishes a theoretical analysis framework based on the theories of agglomeration externalities, environmental Kuznevo curve theory and green development, etc. Based on this research foundation, it elaborates the mechanism of the role of industrial agglomeration and digital transformation on green development. Secondly, a scientific evaluation index system is established to objectively measure the development of each of the three variables using relevant data at the provincial level. Finally, a panel model is constructed to empirically analyze the relationship and effects between the three variables from multiple dimensions.

Since most of the existing studies focus on the influence of industrial agglomeration on green development and the influence of digital economy on green development, few of them focus on the Yangtze River Economic Belt and study the relationship between the three at the same time. Therefore, this paper intends to provide new ideas for enriching the relationship theory, mechanism of action and evaluation measurement methods of industrial agglomeration and digital transformation on green development by establishing the above theoretical analysis framework, so as to provide a reference for the transformation of green development in the Yangtze River Economic Belt. This paper aims to provide reference for the transformation of green development in the Yangtze River Economic Belt and enrich the existing research results from multiple perspectives.

2. Literature Review

2.1 Literature review of industrial agglomeration

(1) The connotation and characteristics of industrial agglomeration

Corning Xu (2001) also proposed the same view that the aggregation of similar industries in a certain region is a manifestation of industrial clusters.[1] Youjin Liu and Lu Cheng Huang (2001) proposed that the concept of industrial agglomeration has various meanings, and most of the existing definitions and definitions are defined from a narrower scope, and they understand industrial agglomeration as a series of similar companies and institutions that gather in a particular region and constitute an organizational form of interactive relationship.[2] Jian Yong Fan (2014) and others proposed that industrial clusters refer to the phenomenon of industries with related relationships in the production, operation and marketing process gathering in a certain area.[3] Qiang Yuan Chen and Qi Liang (2014) pointed out that industrial clusters are a kind of necessary path for economic development, and their characteristics will change in different development periods; therefore, in the whole process of development, the government should take measures to ensure that the development of industries and the development of regional economy promote each other and form a win-win situation.[4]

(2) Evaluation measurement of industrial agglomeration

Krugman (1991) used the Gini coefficient to measure the degree of industrial agglomeration in the United States, and the results showed that industrial agglomeration was more in manufacturing. Using the Gini coefficient, Ellison & Amiti (1999) conducted an empirical analysis of 65 industrial sectors in five European Union member states between 1968 and 1995, and the results showed that there is a positive relationship between economies of scale, the proportion of intermediate input products and industrial clusters, and that the level of industrial cluster development increases with the development of industrial clusters.[5] Barrios et al. (2004) conducted an empirical study of industrial clusters in two countries, Ireland and Portugal, using EG indicators, and the results showed that the clusters in these two countries are more affected by the mobility of firms, and the clusters will become worse with the influx of new industries, while the development of industrial clusters will be accelerated with the gradual exit of backward industries.[6] Alfaro & Chen (2010) conducted a study using DO indicators and found that MNCs have higher industrial agglomeration and their agglomeration is influenced by knowledge, technology spillover, and capital spillover.[7]

(3) Industrial agglomeration and green development

The relationship between industrial agglomeration and green development is in essence a reflection of the influence of industrial agglomeration externalities. Academics have conducted many studies on the relationship between industrial agglomeration and green development, and in general, the following

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three views are included:

Industrial agglomeration plays a positive role in green development. Renfa Yang (2015) conducted an empirical study on the correlation between industrial agglomeration and environmental pollution using a threshold regression model and found that when the degree of agglomeration is greater than a certain threshold, agglomeration will generate positive environmental externalities and thus promote green development.[9] Using spatial measures, Pingtan Zhang and Xiwei Tu (2021) used manufacturing industries in major cities in China from 2004 to 2016 and found that their industrial agglomeration has a significant positive impact on their green development, which is promoted by green technological progress.

Industrial agglomeration plays a negative role on green development. Hao Chang Yang et al. (2020) pointed out that in industrial clusters there are not only negative externalities such as population density and ecological degradation, but also "agglomeration rent" and "policy rent", which have a negative impact on green development.[10] Yongze Yu et al. (2022) Due to the negative effects of resource dispersion, increased production factors, industrial structure consolidation, disruptive innovation and systemic risks generated by manufacturing industry clusters, the degree of green development in agglomerations has decreased significantly.

Industrial clustering plays a non-linear role in green development. Yi Junyuan and Rong Hui Xie (2014) examined the inverted "U" relationship between industrial clusters and environmental pollution from the perspective of environmental externalities, taking the provincial industrial clusters in China from 1999 to 2010 as an example, and positively characterized their regional heterogeneity, in which technological innovation plays a key role in the position of the turning point on the U-shaped curve. Haochang Yang et al. (2020) empirically analyzed the drivers of industrial clustering and green innovation of high-tech enterprises from the perspective of production efficiency, and analyzed the mechanism of action that industrial clustering enhances green production efficiency through high technology spillover and economy of scale effect, and then promotes regional green development.[10]

2.2 Literature review of digital transformation

(1) The connotation and characteristics of digital transformation

With the rapid development of digital technology and the deep integration of the real economy, digital transformation has become the core driver of high-quality economic development, and many scholars at home and abroad have elaborated on the connotation and characteristics of digital transformation based on different perspectives. Kejin Ni et al. (2021) Digital transformation is a process of applying digital information technology to traditional production and operation, thus transforming traditional business processes, and with the development of digital economy, digital transformation of enterprises also arises. Xiaohong Chen et al. (2022) consider the digital economy as an emerging economic activity that is mainly centered on digital information.

(2) Evaluation measurement of digital transformation

The factors of production, infrastructure projects, value outputs and inputs that come with the digital economy are different from the traditional economic model, and its measurement methods are more diverse and emerging, with two main types of direct and indirect methods currently available.

The direct method is to classify specific industries into the scope of the digital economy, and then make a direct estimate of the size of the digital economy in a certain area. The U.S. Department of Commerce categorizes digital infrastructure projects, e-commerce, and digital media, and then ultimately obtains the level of the digital economy by measuring these three categories. The China Communications Research Institute calculated the size of the digital economy by industry classification and then added them up to calculate the overall level of development. The indirect method is to measure the overall level of digital economy development by aggregating the measurement of digital-related industries in each region through multiple dimensions. Huiqun Huang et al. (2019) used four indicators of Internet penetration, related practitioners, related output, and cell phone penetration. Tao Zhao et al. (2020) measured the comprehensive development level of the digital economy in terms of both Internet development and digital financial inclusion.[11] Xianchun Xu et al. (2020) considered that the connotation of digital economy contains four levels, such as digital infrastructure, digital media, digital transactions, and digital economy transaction products.[12]

(3) Study on the relationship between digital transformation on industrial agglomeration and green development

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From the study of the relationship between digital transformation and green development. Xiang Dai et al. (2022) study the driving effect of digital inputs on the green transformation of manufacturing industry from the perspective of digital empowerment. Xiaohong Chen et al. (2022) proposed that the use of emerging digital technologies can promote the development of the manufacturing industry toward intelligence and greening and generate a variety of new business models, thus promoting the greening of the manufacturing industry; in turn, digital transformation can have a direct effect on the greening of the manufacturing industry by improving the degree of green innovation and energy consumption structure of enterprises.

The role of digital transformation on green development in terms of mechanism. In terms of the own attributes of digital transformation, Kunwang Li (2015) argues that ICT innovation driven by it can well drive the development of foreign trade and accelerate the synergistic development of society and economy. Hongwang Cha (2017) showed that digital technology can transform and upgrade traditional energy-intensive industries by improving the efficiency of industrial resource allocation, the efficiency of industrial knowledge flow, and the quality of employees, and thus promote regional green development. Yuanfei Xiao et al. (2021) argue that digital transformation can improve the country's openness, improve the country's industrial structure, and optimize the country's human capital investment, thus improving the country's green development and promoting the country's green development. From the perspective of social public environmental protection, the findings of Yapeng Dai (2021) suggest that the advancement of digital technology will have an indirect contribution to regional green development by changing citizens' perceptions of public environmental protection.

2.3 Literature review of green development

(1) The proposal and connotation of green development

Many scholars and organizations in China and abroad have given different understandings on the concept of green development. In 2011, OECD proposed to improve the level of economic development while ensuring the sustainability of natural resources to provide services to human beings. Di Shang et al. (2020) proposed that green development is a composite system consisting of three subsystems: economic, social, and ecological, and its intrinsic mechanism is still unclear.[13]

(2) Evaluation measurement of green development level

In the construction of the evaluation system, many scholars have measured from different dimensions and conducted empirical analysis. The current evaluation and measurement methods of scholars at home and abroad for green development are more diverse, and there are three main ones with higher recognition. The model method is mainly based on the construction of mathematical and rational models to measure, and Bo Qianglin et al. (2019) measured the level and efficiency of green development by using the super-efficient DEA-SBM model with China's city-level data as sample data. The comprehensive evaluation method assesses the green development status by constructing a scientific and reasonable index system. On this basis, OECD proposed four aspects of resource production efficiency, natural resource base, quality of life and policy response as indicator dimensions to measure the level of green development. The third is an evaluation method that mainly uses principal component analysis and entropy weight method to measure. The indicator system of Lingling Guo et al. (2016) encapsulates five aspects of economic status, environmental quality, quality of life, resource endowment status and policy support. Mo Yang et al. (2021) constructed a measurement system from four dimensions: resource utilization, environmental quality, ecological protection, and policy support.

(3) Influencing factors of green development

Jianhuan Huang (2014) constructed an evaluation measure system of capital support effect, capital allocation effect, enterprise regulation effect and green finance effect, and tested them empirically. Renfa Yang (2019) argues that "directive" and "incentive" environmental regulations can effectively promote green development.[9] Chuanqing Wu (2020) takes the data of green development at provincial level in China as a sample, and empirically finds that the level of openness to the outside world and the degree of environmental governance have a positive effect on green development, while the increase of the share of secondary industry in the industrial structure is not conducive to green development. Wenjun Chen (2021) finds that the level of R&D and the level of tertiary industry development are conducive to promoting the efficiency of green development, and government intervention has both positive and negative effects on green development.

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2.4 Literature Review

Through combing the literature on industrial agglomeration, digital transformation and green development at home and abroad, we initially obtain the current research scope, connotation definition, evaluation measurement and the interrelationship between the three. This paper provides good theoretical guidance and empirical reference for analyzing the relationship and mechanism of the three. Through combing and summarizing the literature, we found that although the existing research has achieved fruitful results, there is still some room for progress, specifically: (1) the existing research literature on industrial agglomeration, digital transformation and green development is mostly based on the relationship between the two, and few studies have analyzed the relationship between industrial agglomeration, digital transformation and green development in the same framework. (2) Domestic and foreign scholars have made a lot of comments on industrial agglomeration, digital transformation and green development. (2) Scholars at home and abroad have not reached a consensus on the relationship between industrial agglomeration, digital transformation and green development, and most of the existing literature only uses empirical evidence to verify the relationship between industrial agglomeration and green development and digital transformation and green development, but lacks theoretical research on the specific mechanism and transmission mechanism of the relationship. (3) The sample data of existing research objects are mostly selected at the national level, individual provinces and cities, prefecture-level cities or regions such as Yangtze River Delta and Pearl River Delta, etc. Fewer studies have focused on the green development of industrial agglomerations in the Yangtze River Economic Belt.

Therefore, based on the shortcomings of the existing literature and in order to better study the influence relationship and mechanism of industrial agglomeration and digital transformation on green development, this paper establishes a corresponding evaluation index system to measure the current situation of each of the three variables on the basis of literature combing and theoretical deduction, and reasonably selects relevant control variables to conduct an empirical analysis using a fixed-effect regression model to explore the influence relationship and heterogeneity patterns of industrial agglomeration and digital transformation on green development among the Yangtze River Economic Belt, the upper, middle and lower reaches of the Yangtze River Economic Belt.

3. Theoretical model

Based on the above theoretical analysis and research hypothesis, a theoretical research model between industrial agglomeration, digital transformation and green development in this paper can be constructed, as shown in Figure 1:

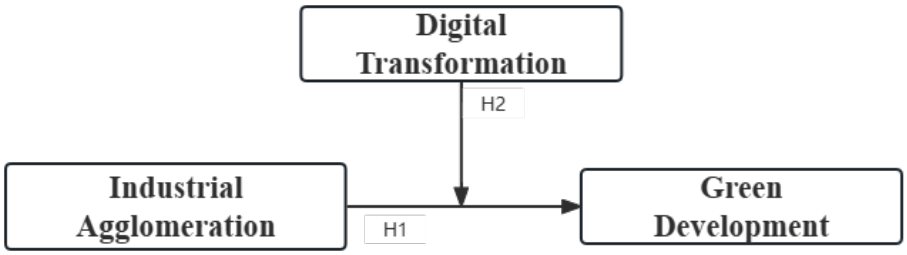

Figure 1 Theoretical research model

4. Study Design

4.1 Sample and data sources

This paper selects 11 provinces and cities along the Yangtze River Economic Belt as research samples, and further divides the Yangtze River Economic Belt into upstream, middle and downstream groups for heterogeneity analysis after the overall study, in order to explore the impact of industrial agglomeration on green development and the moderating role of digital transformation between the two.

The raw data involved in the paper are obtained from the China Statistical Yearbook, China Statistical Yearbook of Industrial Economy, China Statistical Yearbook of Environment, China Statistical Yearbook of Cities and authoritative databases such as CEE and EPS database in the corresponding years, among

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which the digital transformation data are obtained from China Digital Inclusive Finance Index. Interpolation is used to fill in the missing values for relevant data.

4.2 Variable selection and measurement

(1) Explained variables

Green development is concerned with how to make human beings live in harmony with nature, and achieving green development means achieving a win-win situation between economic performance and environmental performance. Therefore, this paper selects indicators from energy consumption improvement, environmental pollution and other aspects to build an evaluation system, and adopts the entropy TOPSIS method to assign weights to each indicator and the comprehensive index of green development of Yangtze River Economic Belt , which is called GD. The specific index system and weighting results are shown in Table 1.

Table 1 Green development evaluation measurement system

Tier 1 Indicators	Secondary indicators	Measurements	Weights	Indicators Properties
Green Development Level	Energy consumption elasticity Coefficient	Energy consumption growth rate / GDP growth rate	**0.137**	-
	Unit output of wastewater	Total wastewater discharge/regional GDP	**0.508**	-
	Unit output of exhaust gas	Sulfur dioxide emissions/regional GDP	**0.123**	-
	Unit output of solid waste	Solid Waste/Gross Regional Product	**0.232**	-

(2) Explanatory variables

In this paper, we use the location entropy calculated by the industrial value added to measure the level of manufacturing agglomeration in the provinces and cities along the Yangtze River Economic Belt, which is recorded as LQ_{it} . The calculation method is as follows:

$$LQ_{it} = \frac{IDV_i / \sum_{i=1}^{n} IDV_i}{GDP_i / \sum_{i=1}^{n} GDP_i}$$

(3) Moderating variables

Table 2 Evaluation indicators of digital transformation level in Yangtze River Economic Zone

Main Indicators	Tier 1 Indicators	Secondary indicators	Metrics	Weights	Indicators Properties
Digital transformation level	Internet Development	Internet penetration rate	Internet per 100 people Number of users	**0.079**	+
		Number of Internet-related employees	Computer Services and Software Percentage of Practitioners	**0.143**	+
		Internet-related outputs	Telecommunications business per capita Total volume	**0.298**	+
		Number of mobile Internet users	Cell phones per 100 people Number of users	**0.074**	+
	Digital Financial Inclusion Development	Digital Financial Inclusion Development Index	Digital Financial Inclusion Development Index	**0.406**	+

Considering the availability of data and the fact that only a small amount of literature is available to measure the level of digital transformation at the provincial and city levels, this paper establishes a digital transformation evaluation index system through five indicators in two dimensions, and uses the entropy TOPSIS method to assign weights to each indicator and a comprehensive index to measure the level of digital transformation development in 11 provinces and cities along the Yangtze River Economic Belt, which is called DIG, and the specific index system and the assignments The results are shown in Table 2.

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(4) Control variables

In order to more accurately assess the overall impact of industrial agglomeration and digital transformation on the green development of the Yangtze River Economic Belt, and to reduce the problem of regression bias caused by omitted variables and the endogeneity problem, the following control variables are selected: (i) government expenditure (GOV), measured by the share of fiscal expenditure in GDP of each province and city; (ii) industrialization level (IND), measured by the share of industrial value added in GDP of provinces and cities measured by the share of industrial value added in the GDP of each province and city; ③level of education (EDU), measured by the average number of students enrolled in higher education schools per 100 people; ④level of R&D investment (RD), measured by the share of internal spending on R&D in the GDP of each province and city; ⑤environmental infrastructure (EI) the green coverage of built-up areas in each province and city.

4.3 Econometric model construction

In order to verify the inverted "U" non-linear relationship between industrial agglomeration and green development in the Yangtze River Economic Zone and the moderating effect of digital transformation in the inverted "U" relationship between industrial agglomeration and green development, this paper introduces industrial agglomeration, the quadratic term of industrial agglomeration and the interaction term of each. In this paper, the quadratic term of industrial agglomeration, the quadratic term of industrial agglomeration and the interaction term of each with digital transformation are introduced into the regression model in equations (1) to (4), and other factors that may affect green development, such as government expenditure, industrialization level, education level, R&D investment level and environmental infrastructure level, are introduced into the model as control variables.

$$GD_{i,t} = \alpha_0 + \alpha_1 LQ_{i,t} + \alpha_2 GOV_{i,t} + \alpha_3 IND_{i,t} + \alpha_4 EDU_{i,t} + \alpha_5 RD_{i,t} + \alpha_6 EI_{i,t} + \mu_i + \nu_i + \varepsilon_{i,t} (1)$$

$$GD_{i,t} = \alpha_0 + \alpha_1 LQ_{i,t} + \alpha_7 LQ_{i,t} * DIG_{i,t} + \alpha_2 GOV_{i,t} + \alpha_3 IND_{i,t} + \alpha_4 EDU_{i,t} + \alpha_5 RD_{i,t} + \alpha_6 EI_{i,t} + \mu_i + \nu_i + \varepsilon_{i,t} (2)$$

$$GD_{i,t} = \alpha_0 + \alpha_1 LQ_{i,t} + \alpha_8 LQ_{i,t}^{\ 2} + \alpha_2 GOV_{i,t} + \alpha_3 IND_{i,t} + \alpha_4 EDU_{i,t} + \alpha_5 RD_{i,t} + \alpha_6 EI_{i,t} + \mu_i + \nu_i + \varepsilon_{i,t} (3)$$

$$GD_{i,t} = \alpha_0 + \alpha_1 LQ_{i,t} + \alpha_8 LQ_{i,t}^{\ 2} + \alpha_9 LQ_{i,t}^{\ 2} * DIG_{i,t} + \alpha_2 GOV_{i,t} + \alpha_3 IND_{i,t} + \alpha_4 EDU_{i,t} + \alpha_5 RD_{i,t} + \alpha_6 EI_{i,t} + \mu_i + \nu_i + \varepsilon_{i,t} (4)$$

where i represents provinces and cities, t represents years, $GD_{i,t}$ represents the level of green development, $LQ_{i,t}$ represents the level of industrial agglomeration, $LQ_{i,t}^2$ is the secondary term of industrial agglomeration, $LQ_{i,t}$ $*DIG_{i,t}$ is the interaction term between the primary term of industrial agglomeration and digital transformation, $LQ_{i,t}^2$ $*DIG_{i,t}$ is the interaction term between the secondary term of industrial agglomeration and digital transformation, $GOV_{i,t}$ represents government expenditure, $IND_{i,t}$ represents the level of industrialization, $EDU_{i,t}$ represents the level of education $RD_{i,t}$ represents the level of R&D investment, $EI_{i,t}$ represents the level of environmental infrastructure, andμ_i represents individual fixed effects, RDγ_i represents time fixed effects, and$\varepsilon_{i,t}$ represents random disturbance term.

5. Empirical analysis

5.1 Descriptive statistics and data testing

(1)Descriptive statistical analysis

Using the panel data of 11 provinces and cities along the Yangtze River Economic Belt from 2011 to 2020, descriptive statistical analysis of the independent, dependent, and control variables was conducted, as shown in Table 3. it can be seen from the table that the standard deviations of most of the main variables are smaller than the mean values, indicating that the variable data are relatively smooth. Among them, the mean value of the dependent variable green development is 0.689, and the difference between the maximum value of green development and its minimum value is large, indicating that there are spatial differences in the green development levels of 11 provinces and cities along the Yangtze River economic belt. From the mean, maximum and minimum values of the core explanatory variable industrial agglomeration, some provinces and cities along the Yangtze River economic belt have formed the advantage of industrial agglomeration. In addition, it is noteworthy that the mean value of digital transformation level is 0.372, the minimum value is 0.077, and the maximum value is 0.855, with large differences, indicating that the uneven development of digital transformation among provinces and cities along the Yangtze River Economic Belt is more obvious.

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Table 3 Descriptive statistics of the main variables

Variable	N	Mean	p50	SD	Min	Max
GD	110	0.689	0.725	0.157	0.222	0.973
LQ	110	0.962	0.983	0.130	0.701	1.189
DIG	110	0.372	0.334	0.177	0.0770	0.855
GOV	110	0.228	0.223	0.0700	0.119	0.402
IND	110	0.362	0.367	0.0630	0.223	0.469
RD	110	0.0180	0.0180	0.00900	0.00600	0.0420
EI	110	40.16	40.22	2.741	32.31	46.81
EDU	110	2.594	2.525	0.560	1.254	3.722

(2)Correlation analysis

The correlation test results in Table 4 show that there is a significant correlation between the independent variable "industrial agglomeration" and the five selected control variables and the dependent variable green development.

Table 4 Correlation analysis of the main variables

	GD	LQ	DIG	GOV	IND	RD	EDU
GD	1						
LQ	0.212**	1					
DIG	0.819***	0.0410	1				
GOV	-0.435***	-0.636***	-0.186*	1			
IND	-0.360***	0.705***	-0.609***	0.482***	1		
RD	0.717***	0.144	0.541***	0.605***	-0.0790	1	
EI	0.229**	0.582***	0.244**	0.411***	0.245***	0.0910	1
EDU	0.716***	0.193**	0.574***	0.513***	-0.132	0.741***	0.320***

Note: * p < 0.1, ** p < 0.05, *** p < 0.01

5.2 Overall Regression Analysis of Yangtze River Economic Zone

The results of the regression based on the overall sample of Yangtze River Economic Zone are shown in Table 5, model (1) (3) are the regression results of the baseline model of this paper, model (2) (4) are the regression results of the moderating effect of this paper, the Hausman test of all four models passed the 1% significance level, so the fixed effect model is used in this paper.

Table 5 Overall regression results for the Yangtze River Economic Zone

	Model(1)	Model(2)	Models(3)	Models(4)
LQ	1.151***	1.667***	3.466***	2.969***
	(0.149)	(0.253)	(0.989)	(0.959)
GOV	0.339	0.109	0.471	0.342
	(0.414)	(0.413)	(0.408)	(0.392)
EDU	0.075*	0.104**	0.064	0.091**
	(0.039)	(0.040)	(0.039)	(0.038)
IND	-2.757***	-3.635***	-2.945***	-3.849***
	(0.349)	(0.490)	(0.349)	(0.444)
RD	-12.600**	-6.146	-12.896**	-7.333
	(5.975)	(6.368)	(5.833)	(5.863)
EI	0.003	0.002	0.001	0.000
	(0.005)	(0.005)	(0.005)	(0.005)
LQ*DIG		-0.388**		
		(0.156)		
LQ^2			-1.152**	-0.537
			(0.487)	(0.506)
LQ^2 *DIG				-0.394***
				(0.128)
_cons	0.429	0.278	-0.578	-0.327
	(0.283)	(0.282)	(0.507)	(0.492)
N	110.000	110.000	110.000	110.000
r2	0.839	0.850	0.849	0.863
r2_a	0.812	0.822	0.821	0.836
Hausman				Prob >chi2

Standard errors in parentheses
* $p < 0.1$,** $p < 0.05$,*** $p < 0.01$

In model (1), the primary coefficient of manufacturing agglomeration is significantly positive at the level of 1% , and in model (3), the primary coefficient of manufacturing agglomeration is still

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significantly positive, while the secondary coefficient is significantly negative at the level of 1%, which indicates an inverted "U" non-linear relationship between manufacturing industry agglomeration and green development in the Yangtze River Economic Zone. Specifically, when the degree of industrial agglomeration is at a low to medium level, industrial agglomeration can positively influence green development through scale effect, knowledge and technology spillover, positive competition effect, and environmental regulation and other positive externalities. In addition, the manufacturing enterprises in the agglomeration area of Yangtze River Economic Zone can share the pollution control facilities, production resource elements, and technical knowledge, while also sharing the expenses and costs generated by environmental control, improving resource utilization efficiency, promoting green process level and green technology innovation on the basis of knowledge and technology spillover, and thus enhancing the green development level of Yangtze River Economic Zone. When the scale of manufacturing agglomeration expands to a certain extent, the manufacturing enterprises in the agglomeration area are overly dense, the supporting facilities and production resources are in short supply, the pollution emissions are increasing, the phenomenon of "free-riding" is common, and the negative externalities of agglomeration such as crowding effect, expansion effect and intensive effect are constantly appearing, which bring negative impacts to the industry in the Yangtze River Economic Zone. The negative externality of industrial agglomeration is far greater than the positive externality, and its impact on green development has also changed from positive to negative, which inhibits the improvement of green development in the Yangtze River Economic Zone.

Model (2)(4) is the regression result after introducing the interaction term of the primary and secondary terms of industrial agglomeration with the moderating variable of digital transformation, respectively, and the results show that the coefficient of the interaction term of the moderating effect in both models is always significantly negative at the 1% level. This indicates that digital transformation plays a positive moderating role in the inverted U-shaped relationship between industrial agglomeration and green development, and the relationship between industrial agglomeration and green development will be strengthened when the degree of digital transformation in the industrial agglomeration area is high, and the shape of the whole inverted U-shaped curve will be steeper. The reason is that in the early stage of industrial agglomeration, digital transformation can improve the allocation efficiency of various production factors and resources within the industrial agglomeration of the Yangtze River Economic Zone, avoiding additional energy consumption and environmental damage while developing the economy, and digital technology can strengthen the knowledge and technology spillover within the manufacturing agglomeration of the Yangtze River Economic Zone by breaking the traditional technology pattern and innovation technology, which is conducive to improving the level of green technology innovation. In addition, digitalization can realize industrial agglomeration over long distances, and to a certain extent, non-spatial agglomeration can be realized to expand the industrial agglomeration area and further bring into play the positive externality of agglomeration. The above favorable effects brought about by digital transformation together positively strengthen the promotion of green development in the early stage of industrial agglomeration. In the late stage of industrial agglomeration, the negative externality of agglomeration is generated, and the release of the "dividend effect" brought by digital transformation is slowed down, and there is a possibility of digital inequality and the "digital divide" in the agglomeration area. In the process of digitalisation, the flow of production factors from peripheral cities to central cities may be accelerated, resulting in a "siphon effect", leading to a "horse-trust effect" in which "the weak are weaker and the strong are stronger". These digital transformations have a negative effect on the green development of the Yangtze River Economic Zone in the later stages of industrial agglomeration.

In terms of control variables, the industrialization level (IND) in models (1) to (4) is always significantly negative at the 1% level, indicating that the impact of industrialization level on the green development of the Yangtze River Economic Zone is negative, i.e., the lower the industrialization level in the industrial agglomeration area, the more it is conducive to the improvement of the green development level of the area; the education level (EDU) is significantly positive in models (1) (2) (3), indicating that The coefficient of education level (EDU) in model (1)(2)(3) is significantly negative at the 5% level, indicating that regardless of the variation of main and moderating effects, the increase of education level in the agglomeration area can positively promote the green development level of Yangtze River Economic Zone; the coefficient of R&D investment level (RD) in model (1)(3) is significantly negative at the 5% level, the object of this paper is the industrial agglomeration phenomenon of manufacturing industry in Yangtze River Economic Zone, the attributes of manufacturing industry determine that the R&D investment of such enterprises often brings high energy consumption and The attribute of manufacturing industry determines that the R&D investment of such enterprises often brings high energy consumption and high pollution, and their R&D investment applied to green innovation technology accounts for a relatively small proportion, so it will present the phenomenon that the R&D

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investment of manufacturing industry is not conducive to the green development of Yangtze River Economic Zone.

To further investigate the impact of industrial agglomeration on green development under different levels of digital transformation, this paper divides the level of digital transformation and industrial agglomeration into two different levels, high and low, to describe the impact of digital transformation as a moderating variable on industrial agglomeration and green development. As shown in Figure 5, the inverted "U" curve between industrial agglomeration and green development in the high digital transformation scenario is steeper than that in the low digital transformation scenario, i.e., as the level of digital transformation increases, the inverted "U" curve between industrial agglomeration and green development is significantly strengthened. "The inverted U-shaped relationship between industrial agglomeration and green development is significantly strengthened as the level of digital transformation increases.

6. Conclusions of the study

This paper takes 11 provinces and cities along the Yangtze River Economic Belt from 2011 to 2020 as the research sample, and focuses on the impact of industrial agglomeration on green development and the moderating effect of digital transformation in the Yangtze River Economic Belt to systematically study and interpret the following conclusions:

First, the manufacturing agglomeration level, digital transformation level and green development level of the Yangtze River Economic Belt show different characteristics between 2011 and 2020, and all of them have obvious spatial distribution differences. In terms of manufacturing agglomeration level , the overall manufacturing location entropy of 11 provinces along the Yangtze River Economic Belt fluctuates around 1, with most provinces and cities showing an upward trend and a small number of provinces and cities showing a downward trend, indicating that most provinces and cities in the Yangtze River Economic Belt have certain agglomeration advantages in manufacturing industry nationwide, but there is still room for improvement . In terms of digital transformation, the overall digital transformation in Yangtze River Economic Zone is developing at a high speed, and the digital transformation development index is improving. In terms of green development level, with the implementation of green development concept, the overall green development of Yangtze River Economic Belt is getting higher and higher, the growth rate continues to slow down but the overall development is steadily improving, and the average annual growth rate of green development is all positive.

Second, the impact of industrial agglomeration on green development in the Yangtze River Economic Zone is a complex inverted "U" non-linear characteristic with regional heterogeneity. Specifically, there is a significant inverted U-shaped relationship between industrial agglomeration and green development in the Yangtze River Economic Zone as a whole, which means that moderate industrial agglomeration can drive regional green development well, but when the agglomeration exceeds a certain level, excessive agglomeration and capacity expansion will inhibit regional green development.

Third, the improvement of digital transformation in the Yangtze River Economic Zone can positively regulate the inverted U-shaped relationship between industrial agglomeration and green development, but there is regional heterogeneity. Specifically, digital transformation in the early stages of industrial agglomeration in the Yangtze River Economic Zone can enhance resource allocation efficiency, break traditional innovation and technology models, and achieve non-spatial agglomeration to positively strengthen the promotion of green development in the early stages of industrial agglomeration; however, in the later stages, the release of the "dividend effect" brought by digital transformation becomes slower and may produce agglomeration However, in the later stage, the "dividend effect" brought by digital transformation becomes slower and may generate digital inequality, "digital divide" and "siphon effect" in the agglomeration area, which in turn inhibit green development.

Fourth, the impact of other factors on the green development of the Yangtze River Economic Belt. Specifically, the industrialisation level of the Yangtze River Economic Zone as a whole is always significantly negative at the 1% level, which is not conducive to green development; the education level is always significantly positive, indicating that the improvement of regional education level can positively promote green development; the R&D investment level is significantly negative at the 5% level, which is due to the fact that the attributes of the manufacturing industry, which is the subject of this study, determine that the R&D investment of such enterprises often brings high energy consumption, high pollution and its application to green development, The reason for this is that the attributes of the manufacturing industry in this study determine that the R&D investment of such enterprises often brings

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high energy consumption and high pollution, and the R&D investment applied to green innovation technology is relatively small, thus showing the phenomenon that the R&D investment in manufacturing industry is not conducive to the green development of the Yangtze River Economic Zone.

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