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Research on the impact of digital finance on the green development level of manufacturing industry

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Abstract: *The essential requirement of Chinese modernization is to achieve high-quality development and harmonious coexistence between man and nature. In this context, based on panel data from 30 provinces from 2012 to 2021, this article studies the impact of digital finance on the green development of the manufacturing industry from different perspectives, and explores possible ways for digital finance to empower the green development of the manufacturing industry. This article first uses the SBM model to measure the green development level of my country's manufacturing industry, and analyzes the spatiotemporal evolution characteristics of digital finance and manufacturing green development levels. Next, using a two-way fixed effects model, this paper finds that digital finance has a significant positive role in promoting the green development of the manufacturing industry. The robustness of the core conclusions of this article is proved by excluding regional panels and time panels. Heterogeneity analysis shows that the positive impact of digital finance on the green development of manufacturing is strongest in the eastern region, followed by the central region, and weakest in the western region. Based on the above research, this article proposes improvement paths and policy recommendations to establish a green manufacturing digital financial ecosystem to promote digital finance to empower the green development of the manufacturing industry.*

Keywords: *Digital Finance, Manufacturing Industry, Green Development, SBM Model*

1. Introduction

The essential requirements of Chinese-style modernization include achieving high-quality development and promoting the harmonious coexistence between man and nature. As the pillar industry of my country's economy, manufacturing plays an indispensable role in economic growth, technological innovation, international competitiveness and the creation of job opportunities. Under the goal of Chinese-style modernization, it is a very necessary historical task to develop green and high-quality manufacturing to build a modern and powerful country. As the global climate change problem intensifies, green development has become a common goal for countries around the world. As the world's largest manufacturing country, the green development of manufacturing has great theoretical value and practical significance, so it has always been one of the hot spots in academic research. Existing research on the green development of the manufacturing industry mainly focuses on the measurement of the green development of the manufacturing industry and the influencing factors that promote the green development of the manufacturing industry. Most of the existing studies indirectly explore the impact of digital finance on the green development of the manufacturing industry, but there are few studies directly on the green development level of digital finance and the manufacturing industry. Based on the background of Chinese modernization, this paper directly explores the relationship between digital finance and the green development level of the manufacturing industry, which makes up for the gap in the research field to a certain extent[1-7].

2. Manufacturing Green Development Level Measurement Model Based on SBM

2.1. Model Establishment

Total factor productivity is a variable that is conducive to economic growth (the value may be negative, zero or positive), including economic policies, the role of the government in the economy, work attitudes, positive external effects caused by an educated labor force, Technical learning, etc. This article uses green total factor productivity to measure the green development level of urban manufacturing, and uses the SBM efficiency measurement method for calculation. The SBM (Slacks-Based Measure) efficiency

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measurement method is a non-radial efficiency measure in the DEA efficiency measurement method. Its advantage is that it directly measures excess input and insufficient output, and the distance between input and output to the production frontier. It is called slacks to measure efficiency. The specific principles are as follows:

Assume n decision-making units (DMU), and each decision-making unit consists of 3 vectors, input vector, expected output vector and undesired output vector, respectively expressed as$x \in R_m$、$y^g \in R_{s1}$、$y^b \in R_{s2}$;

Define matrices as$X$, Y^g , Y^b as$X = (x_{i,j}) \in R_{m\times n}$, $Y^g = (y_{ij}^g) \in R_{s1\times n}$, $Y^b = (y_{ij}^b) \in R_{s2\times n}$ respectively. According to the actual input and output, it is assumed that the production possibility set of $X > 0$, $Y^g > 0$, $Y^b > 0$is P , that is, Nkinds of factor inputs XAll combinations of desired and undesired outputs produced can be defined as:

$$P = \{(x, y^g, y^b) | x \geq X\lambda, y^g \geq Y^g, \lambda y^b \geq Y^b\lambda, \lambda \geq 0\} \tag{1}$$

According to the definition, adding SBM-Undesirable of undesired output, the model is as follows:

$$\rho^* = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{m} S_i^- / X_{i0}}{1 + \frac{1}{S_1 + S_2}\left(\sum_{r=1}^{S_1} S_r^g / y_{r0}^g + \sum_{r=1}^{S_2} S_r^b / y_{r0}^b\right)} \tag{2}$$

$$\text{s.t.} \begin{cases} X_0 = X\lambda + S^-;\ y_0^g = Y^g\lambda + S^g;\ y_0^b = Y^b\lambda + S^b \\ S^- \geq 0,\ S^g \geq 0,\ S^b \geq 0,\ \lambda \geq 0 \end{cases} \tag{3}$$

In the formula,S_i^- ,S_r^g ,$S_r^b$are respectively the input redundancy, positive output deficiency and by-product superscalar amount of the$i_0$decision-making unit DMU,S^- ,S^g ,$S^b$are their corresponding vectors,λ are the weight vectors,$\rho^*$are the objective functions and are strictly decreasing , and$0 \leq \rho^* \leq 1$.

When$\rho^* = 1$, that is,$S^- = 0$,$S^g = 0$,$S^b = 0$, the decision-making unit is efficient;

When$\rho^* < 1$, that is,S^-,S^g,S^b, at least one of the three is not equal to zero, the decision-making unit is inefficient, and there is The need for improvements in input and output. Since the model is a nonlinear programming model, it is converted into a linear programming model according to the Charnes-Cooper conversion method for solution.

2.2. Data Sources and Variable Selection

In this study, taking into account the availability and completeness of data, 30 provinces were selected as research samples (due to lack of data in Hong Kong, Macao and Taiwan(China), they were not used as samples for this empirical study). The original data used mainly came from 2012-2022 Provincial Statistical Yearbook, "China Statistical Yearbook" and "China Environmental Statistical Yearbook".

Table 1: Input-output factors

Feature dimensions	category	Specific indicators	Index unit
input factors	energy input	Manufacturing energy consumption	10,000 tons of standard coal
	labor input	Average manufacturing employment	Thousands of people
	capital investment	capital stock	billion
output factors	expected output	Manufacturing value added	billion
	undesirable output	Comprehensive pollution index	

This article uses green total factor productivity to measure the green development level of urban manufacturing, and uses the SBM efficiency measurement method for calculation. The selected specific input-output factor indicators are shown in *Table 1*.

2.3. Calculation Results of Green Development Level of Manufacturing Industry

Due to space limitations, this article only displays descriptive statistics on the green development level of the manufacturing industry in each province and city in each year. Descriptive statistics are in *Table 2* .

ISSN 2616-5902 Vol. 6, Issue 7: 198-204, DOI: 10.25236/AJBM.2024.060727

Table 2: Descriptive statistics on the level of green development in the manufacturing industry

year	sample size	average value	standard deviation	minimum value	maximum value
2012	30	0.552	0.263	0.169	1.033
2013	30	0.503	0.209	0.164	0.925
2014	30	0.516	0.218	0.168	0.960
2015	30	0.510	0.216	0.170	0.971
2016	30	0.511	0.219	0.173	1
2017	30	0.523	0.226	0.178	1
2018	30	0.537	0.234	0.181	1.005
2019	30	0.532	0.234	0.184	1.001
2020	30	0.539	0.236	0.187	1
2021	30	0.545	0.238	0.193	1.000

As can be seen from the table, the level of green development in the manufacturing industry fluctuates from year to year.

3. Research Design

3.1. Variable Setting and Data Sources

3.1.1. Explained Variable

Green development level of manufacturing industry (*GTFP*). This paper uses the calculated green total factor productivity calculated based on the SBM distance function for characterization.

3.1.2. Explanatory Variables

Digital Finance (*DIF)*. The "Peking University Digital Financial Inclusion Index" [8] released by the Peking University Digital Finance Research Center scientifically and comprehensively reflects the current development status of digital finance in my country and can be used as a representative of the development level of digital finance. This article selects the The comprehensive index (DIF) measures the development level of the digital economy.

3.1.3. Control Variables

This article selects the following variables that can affect the green development of the manufacturing industry as control variables.

Economic development level (*Eco)*. The level of regional economic development can affect the level of factor flow and thus affect production efficiency to a certain extent[9]. It is one of the important indicators affecting the green development of the manufacturing industry. This indicator is expressed by the per capita GDP of each province, the unit is 10,000 yuan, and the per capita GDP is used as the indicator description for subsequent quantitative analysis.

Industrial upgrading (*IA*). Industrial upgrading can, to a certain extent, influence the development of the manufacturing structure in a green direction. This variable is expressed by the ratio of the output value of the tertiary industry to the output value of the secondary industry in each province and city[10]

Urbanization level (*Urb*). The process of urbanization has accelerated the development of the manufacturing industry. As environmental awareness has increased in recent years, the concept of sustainable development has become a major trend, which is conducive to the progress of the manufacturing industry in the direction of green development, recycling, environmental protection, and sustainable development[11].

Foreign direct investment (*FDI*). In addition to the needs of China's internal economic development, international investment also promotes the rapid development of China's manufacturing industry[12]. Among them, foreign investment cannot be ignored as one of the factors that promote the further development of manufacturing industry, so it is expressed by the proportion of my country's actual utilization of foreign investment in GDP.

Social consumption level (*Cons*). The increase in consumption levels reflects the upgrading of the demand side to a certain extent and will drive the transformation and upgrading of the manufacturing industry on the production side[13]. This variable is represented by the ratio of consumption to GDP.

ISSN 2616-5902 Vol. 6, Issue 7: 198-204, DOI: 10.25236/AJBM.2024.060727

Financial development level (*Fin*). The level of financial development will affect the sources of investment in the manufacturing industry[14], which will in turn affect the green development process of the manufacturing industry. It is represented by the ratio of the sum of deposits and loans to GDP.

Descriptive statistics for the variables are shown in Table 3.

Table 3: Descriptive statistics of variables

Variable	sample size	average value	standard deviation	minimum value	maximum value
DIF	300	2.505	0.877	0.615	4.590
GTFP	300	0.527	0.227	0.164	1.033
IA	300	1.283	0.711	0.549	5.297
Urb	300	0.602	0.118	0.363	0.896
Eco	300	12,770	8,145	5,423	48,075
FDI	300	0.0183	0.0144	1.00e-04	0.0796
Cons	300	0.384	0.0690	0.222	0.538
Fin	300	3.331	1.150	1.568	8.131

3.2. Model Establishment

3.2.1. Baseline Model

Based on the research assumptions and selected variables of this article, the following benchmark model is established to explore the possible role of digital finance on the green development of manufacturing:

$$GTFP_{i,t} = \alpha_0 + \alpha_1 DIF_{i,t} + \alpha_2 Control_{i,t} + \gamma_i + \vartheta_t + \mu_t + \varepsilon_{i,t} \quad (4)$$

Among them, the explained variable $GTFP_{i,t}$ represents the green development level of manufacturing industry in the province i in the year t ; the explanatory variable $DIF_{i,t}$ represents the province i, year t digital financial index; $Control_{i,t}$ represents control variables; ϑ_t, μ_t respectively control individual and time fixed Effect; $\varepsilon_{i,t}$ is a random disturbance term.

4. Result Analysis

4.1. Baseline Regression Results

The benchmark regression results of digital finance on the green development level of the manufacturing industry are shown in the Table 4 below. Model (1) is a univariate regression that controls year fixed effects. On this basis, model (2) adds province fixed effects, and further adds control variables to obtain model (3). The results show that digital finance has a positive and significant effect on the green development of the manufacturing industry in the three models, indicating that digital finance has a positive impact on the green development of the manufacturing industry. Specifically, for every 100-point increase in the digital financial index, the level of green development in the manufacturing industry will increase by 23.18 points.

Table 4: Baseline regression results

Variable	(1)	(2)	(3)
	GTFP	GTFP	GTFP
DIF	0.2362^{***} (0.0881)	0.2311^{**} (0.0939)	0.2318^{**} (0.0939)
Eco			0.0000 (0.0000)
IA			-0.0005 (0.0117)
Urb			-0.1235 (0.0914)
FDI			0.4922 (0.3883)
Cons			-0.0701 (0.0614)

ISSN 2616-5902 Vol. 6, Issue 7: 198-204, DOI: 10.25236/AJBM.2024.060727

Fin			0.0071 (0.0045)
Province		YES	YES
Year	YES	YES	YES
$\_cons$	0.3105***	0.3157***	0.3664***
	(0.0866)	(0.0875)	(0.0666)
N	300	300	300
$Adj.R^2$		0.1843	0.1926

Note: * p < 0.1, ** p < 0.05, *** p < 0.01, the clustering robust standard errors are in parentheses, the same below.

4.2. Robustness Test and Heterogeneity Analysis

4.2.1. Robustness Test

In order to ensure the robustness of the benchmark regression results, this article uses the following method to conduct robustness testing.

Start by culling the region panel. Our country has a vast territory, and there are large differences in economic development and technological levels between regions, which may have an impact on the green development of digital finance in the manufacturing industry. Therefore, this article eliminates the samples of the four major municipalities with developed economies and the five major autonomous regions that are relatively backward, and conducts a new two-way fixed regression. The results are shown in column (1) of the table below. After excluding the panel, the impact of digital finance on the green development level of the manufacturing industry is significantly positive at the 1% level, indicating that the core conclusion of this article is robust.

Then remove the time panel. Then delete the time panel. This paper considers the policy implications of elevating digital finance to the national strategic level in 2013, which may have a heterogeneous impact on the green development of the manufacturing industry. Based on this, this article eliminates the sample data in 2013 and before, and conducts two-way fixed regression analysis on the remaining panel data. The results are shown in model (2) in Table 5.

4.2.2. Heterogeneity Analysis

In order to further explore the impact of digital finance on the green development of the manufacturing industry in different regions, this article divides the samples of each province and city into the eastern region, the central region and the western region according to geographical location and then conducts a group regression of digital finance on the green development level of the manufacturing industry. The regression results are shown in columns (3) (4) (5) of the Table 5 below. By comparing the group regression results, it is found that the role of digital finance in the eastern and central regions on the green development of the manufacturing industry is positively significant at the 10% level. However, the role of digital finance in the western region on the green development of manufacturing is not significant. Further comparing the coefficient of digital finance in the eastern region and the central region, it is found that the coefficient of digital finance in the central region is greater than that in the eastern region. The above results show that digital finance has the strongest promotion effect on the green development of the manufacturing industry in the eastern region, followed by the central region, and the weakest in the western region. The possible reason is that the eastern region has a strong foundation for digital financial development and green manufacturing development. Digital finance brings stronger factor flow effects to the eastern manufacturing industry, which further empowers the transformation and upgrading of the manufacturing industry. However, the development of digital finance in the western region is limited and the manufacturing foundation is relatively weak, so the interaction between the two is not significant. The level of digital finance and the level of green manufacturing development in the central region is between the two, and the impact is also at a medium level.

Table 5: Robustness test and heterogeneity analysis results

Variable	(1)	(2)	(3)	(4)	(5)
	Cull Area Panel	Cull Time Panel	East Region	Central Region	West Region
DIF	0.2305*** (0.0830)	0.2030** (0.0738)	0.2321* (0.1223)	0.3591* (0.1983)	-0.0648 (0.0519)
Eco	0.0000 (0.0000)	0.0000 (0.0000)	0.0000* (0.0000)	-0.0001** (0.0000)	-0.0000** (0.0000)
IA	-0.0028	-0.0003	-0.0159	-0.0234	-0.0007

	(0.0053)	(0.0051)	(0.0114)	(0.0370)	(0.0099)
Urb	-0.0650 (0.0862)	-0.0334 (0.0370)	-0.3817* (0.2102)	-0.9054 (0.9850)	0.0543 (0.0370)
FDI	-0.0836 (0.3457)	-0.1076 (0.1420)	1.0789 (0.9586)	-1.1224 (1.2557)	-0.1827 (0.3794)
Cons	-0.0835 (0.0720)	-0.0718 (0.0727)	-0.1094* (0.0561)	-0.0963 (0.1341)	0.0442 (0.0411)
Fin	0.0066 (0.0070)	0.0063 (0.0076)	0.0182 (0.0116)	-0.1539* (0.0870)	-0.0133** (0.0049)
Province	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
$\_cons$	0.3580*** (0.0842)	-0.1957 (0.2731)	0.4852*** (0.1107)	0.6995 (0.4603)	0.8464*** (0.2111)
N	220	229	130	70	100
$Adj.R^2$	0.2410	0.3310	0.1492	0.2546	0.6928

Note: * p < 0.1, ** p < 0.05, *** p < 0.01, the clustering robust standard errors are in parentheses, the same below.

5. Conclusions and Suggestions

5.1. Conclusion

This article uses panel data from 30 provinces and cities from 2012 to 2021 as a sample to explore the impact of digital finance and the green development of manufacturing under the background of Chinese modernization. First, the SBM-DEA model was used to calculate the green development level of the manufacturing industry, and the two-way fixed effects model was used to explore the relationship between digital finance and the green development level of the manufacturing industry, and the following conclusions were drawn:

Digital finance has a positive role in promoting the green development of manufacturing industry. The two-way fixed effects model and results set up in this article show that digital finance can positively affect the level of green development of the manufacturing industry. This is the core conclusion of this article.

The positive impact of digital finance on the green development of manufacturing has regional heterogeneity. Heterogeneity analysis shows that digital finance has the strongest promotion effect on the green development of manufacturing in the eastern region, followed by the central region, and the weakest in the western region.

5.2. Suggestions

Based on the research conclusions on digital finance and green development of manufacturing industry, this article gives the following suggestions.

5.2.1. Establish a Green Manufacturing Digital Financial Ecosystem

Establishing a green manufacturing digital financial ecosystem is the key for digital finance to promote the green development of manufacturing. The government should increase its support for the digital financial ecosystem and encourage digital financial institutions to cooperate with manufacturing companies to jointly build a digital financial ecosystem. At the same time, digital financial institutions can provide financial services and support manufacturing companies in their green transformation and upgrading. Manufacturing companies can obtain more convenient and efficient financial services through digital financial platforms, improve their financing capabilities and operating efficiency, and achieve green development. On the one hand, relevant policies are formulated to encourage digital financial institutions to carry out green financial business, and a green financial evaluation mechanism is established to evaluate and supervise the green financial business of digital financial institutions, providing an important guarantee for digital finance to promote the green development of the manufacturing industry. On the other hand, strengthen the supervision of digital financial institutions and establish a green financial risk management mechanism. Digital financial institutions should evaluate and monitor the green transformation and upgrading of manufacturing enterprises through the green financial assessment mechanism, and provide scientific and accurate information for manufacturing enterprises.

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