

Research on Green Production of the Iron and Steel Industry Based on DDF-BML Model

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Abstract: Although the iron and steel industry serves as the pillar industry of national economic development, the negative effects of its high emission and high pollution characteristics on the environment cannot be ignored. In order to achieve the carbon peaking and carbon neutrality goals at an early time and implement five priority tasks, including cutting overcapacity, reducing excess inventory, deleveraging, lowering costs and strengthening areas of weakness, it is urgent to realize the green production of the iron and steel industry. This paper takes listed iron and steel companies from 2016 to 2019 as research samples, and applies the two-stage Malmquist index based on the directional distance function (DDF) to measure the green total factor productivity (GTFP) of iron and steel enterprises. From macro and micro perspectives, the empirical model is used to explore the main influential factors of gtfp. The empirical results show that the overall gtfp growth rate of iron and steel enterprises is not ideal, falling behind at the end of the manufacturing industry. The promotion effect of R&D investment is limited, and the environmental carrying capacity of the production cluster area is approaching the limit. Based on the above empirical results, this paper proposes the following workable implementation path to the realization of the green production of iron and steel industry: On the one hand, the iron and steel enterprises should pay attention to improve technical efficiency, constantly improve low-carbon production process, optimize industrial layout. On the other hand, the government should guide the digital and intelligent development of the iron and steel industry and strengthen supervision to ensure the safety and stability of the supply of resources in the iron and steel industry.

Keywords: The green production; The iron and steel enterprises; The green total factor productivity.

1. Introduction

Since reform and opening up, China has made remarkable achievements in economic development. However, the problem of deteriorating environmental pollution has gradually become a bottleneck restricting the sustainable development of social economy. To this end, General Secretary Xi Jinping has repeatedly stressed that “Clear waters and green mountains are as good as mountains of gold and silver”. In this background, how to achieve a win-win between economic growth and pollution control has become a key issue to be urgently solved by the society and enterprises.

As an important basic industry of the national economy, the iron and steel industry has made leap-forward development in the process of rapid industrialization. By the end of 2020, China’s steel production has reached 1.065 billion tons, which is 66 million times of the early days of the founding of the People’s Republic of China, and accounts for 57% of the global proportion. However, there are many problems with the development of China’s iron and steel industry, such as overcapacity, low resource utilization rate, low industrial concentration, etc. These problems not only limit further development of the iron and steel industry, but also cause inestimable losses to the environment. Relevant data showed that the carbon emissions of China’s iron and steel industry accounted for 18% of China’s total carbon emissions, and over 60% of that of the global iron and steel industry. Therefore, it is imperative to explore the green development quality of iron and steel industry and explore its green strategic transformation path.

Based on this background, this paper takes China’s listed iron and steel companies from 2016 to 2019 as the research sample, uses DDF-based two-stage Malmquist index to

measure the green total factor productivity of iron and steel enterprises, and analyzes the influencing factors of green total factor productivity of iron and steel enterprises from macro and micro perspectives, to explore the scientific realization path of the green production of iron and steel industry.

2. Theoretical Basis and Literature Review

Green production means that under the guidance of green management concept with the orientation of high technology, less pollution and low resource consumption, enterprises promote greenization in processes of development, production and sales, and cultivate green enterprise culture. At present, although there are many studies on green economy, sustainable development and other related concepts, there are few pieces of literature that directly study greenization from the perspective of enterprise strategic management.

Research on green production falls into two major categories. The first category is to carry out a comparative study on the implementation methods of green strategy. For example, Fan et al. discussed the nonlinear impact of various types of environmental regulation means on green technological innovation and green economy, and concluded that the use of market-motivated environmental regulation means to drive green technological innovation is the focus of China’s green economic transformation [1]. Ponikarova et al. discussed the complexity of enterprise green innovation management measures, examined the relationship between various departments in the process of enterprise sustainable strategic management, estimated the restriction conditions of innovation quality improvement, and proposed a new evaluation model to help improve management quality [2]. The second category is the study of greenization itself,

including the study on greenization level and the influencing factors of green development [3]. Li used entropy method to measure the level of green development of energy at the provincial level, and constructed a green evaluation model with five dimensions including energy production structure, consumption structure, clean energy substitution, energy saving and consumption reduction, as well as environmental coordination [4]. Li et al. used the SMBM-DEA model to measure the green total factor productivity of each region and investigated the factors affecting regional economic growth under the constraint of carbon emissions. They found that industrial agglomeration, scientific and technological progress and human resources play a significant role in promoting regional green economic growth, while energy consumption efficiency, investment efficiency and export product structure have a restrictive effect on regional economic development [5]. Du et al. put forward that the strong will of the government and the public to improve living standards is an important reason for the low levels of greenization in developing countries, emphasized the significance of not only developing green innovation technology, but also promoting its wide application, and put forward that measures such as cross-economy green technology transfer can be taken to strengthen the global cooperation of green technology [6].

As a typical industry with high pollution and high energy consumption, iron and steel industry is the focus of many scholars in academia and industry. Some scholars paid attention to enterprise internal factors and industry characteristics: Du et al. found that the asset-liability ratio and R&D level of iron and steel enterprises are closely related to the green development level of the enterprises [7]. Zheng et al. established the business model innovation system of iron and steel industry according to the characteristics of the iron and steel enterprises, and their empirical study found that iron and steel enterprises in South China, East China, central China should continue to increase R&D and innovation, enterprises in North China and Northeast China should optimize enterprise capital structure, and enterprises in Northwest China and Southwest China should focus on the improvement of enterprise profitability [8]. Meanwhile, many scholars focused on environmental regulation: Gao et al. focused on energy saving and emission reduction measures of China's iron and steel industry and carried out an analysis on co-control effectiveness evaluation [9]. Nechifor et al. analyzed the recycling plan and industry structural adjustment policy in China's iron and steel industry, and found that relevant policies helped China's iron and steel industry achieve a stable transformation and closer international green development partnership [10]. Wang et al. found that China's environmental regulations play a decisive role in alleviating air pollution in iron and steel industry [11]. Liu et al. used word frequency analysis and semantic network analysis to focus on the evolution of the five-year plan for the iron and steel industry, and found that the industrial concentration and labor productivity of the main industry did not meet the expected policy objectives [12].

3. Empirical Strategy and Sample Selection

3.1. Model selection and construction

3.1.1. Two-stage Malmquist index based on DDF

The concept of total factor productivity (TFP) was first proposed in the study of the contribution of Solow's residual value to economic growth, which is usually interpreted as the productivity level after deducting the contribution of factor or

the contribution of non-productive input such as technological progress and institutional improvement in output growth, and is widely used in the study of enterprise performance. With the deepening of research, more and more scholars believe that energy and environment are also rigid constraints of economic development. Therefore, when using TFP to evaluate economic performance, besides capital and labor input, both energy input and undesired output should also be taken into consideration [13]. The concept of green total factor productivity was born from this.

In terms of measurement, Malmquist index method is one of the mainstream measurement methods of total factor productivity, which is proposed by Caves et al. (1982) and constructed by the ratio of distance function. However, this method cannot consider the situation of unexpected output. However, DDF-Malmquist proposed by Chung et al. (1997) can accurately estimate gtfp. The core idea of this method is to increase the expected output to a great extent while reducing the input and unexpected output. The specific directional distance function is:

$$\bar{D}(x, y, b; g) = \max \{ \beta : (x - \beta \bar{g}_x, y + \beta \bar{g}_y, b - \beta \bar{g}_b) \in T(x) \} \quad (1)$$

Where $g = (-\bar{g}_x, \bar{g}_y, -\bar{g}_b)$ refers to the direction vector that input and output should scale, and β represents inefficiency.

$$T(x) = \{(x, y, b) : \sum_{n=1}^N Z_n X_{mn} \leq X_m, m = 1, \dots, M$$

$$\sum_{n=1}^N Z_n Y_{sn} \geq Y_s, s = 1, \dots, S \quad (2)$$

$$\sum_{n=1}^N Z_n b_{jn} = b_j, j = 1, \dots, J$$

$$Z_n \geq 0, n = 1, \dots, N$$

Combining equations (1) and (2), the value of $\bar{D}(x, y, b; g)$ can be calculated by solving the following DEA model and measuring the environmental inefficiency value of each DMU.

$$\bar{D}(x, y, b; g) = \max \beta$$

$$s. t. \sum_{n=1}^N Z_n X_{mn} \leq X_m - \beta g_{xm}, m = 1, \dots, M$$

$$\sum_{n=1}^N Z_n Y_{sn} \geq Y_s + \beta g_{ys}, s = 1, \dots, S \quad (3)$$

$$\sum_{n=1}^N Z_n b_{jn} = b_j - \beta g_{bj}, j = 1, \dots, J$$

$$Z_n \geq 0, n = 1, \dots, N$$

$$\beta \geq 0$$

However, DDF-Malmquist index method has the problem of infeasible solution, which will lead to the loss of sample size. Therefore, this paper refers to the two-stage Malmquist index method proposed by Wang Bing (2013). This method can not only solve the problem of infeasible solutions, but also consider the situation of technological regression, so it is more suitable for this study. The specific formula is:

$$BML_t^{t+1} = \frac{1 + \bar{D}_0^B(x^t, y^t, b^t; y^t, -b^t)}{1 + \bar{D}_0^B(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}$$

$$= \left[\frac{1 + \bar{D}_0^B(x^t, y^t, b^t; y^t, -b^t)}{1 + \bar{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \right]$$

$$\times \left[\frac{1 + \bar{D}_0^B(x^t, y^t, b^t; y^t, -b^t)}{1 + \bar{D}_0^B(x^t, y^t, b^t; y^t, -b^t)} \times \frac{1 + \bar{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}{1 + \bar{D}_0^B(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \right] \quad (4)$$

3.1.2. Construction of econometric model

In order to accurately investigate the influencing factors of gtfp in iron and steel enterprises, this paper constructs the following measurement model:

$$GTFP_{it} = \alpha + \beta_0 \cdot RD_{it} + \beta_1 \cdot Lev_{it} + \beta_3 \cdot \ln Scale_{it} + \beta_4 \cdot \ln GDP_{it} + \beta_5 \cdot IS_{it} + \beta_6 \cdot \ln ER_{it} + \delta_i + \eta_t + \mu_{it} \quad (5)$$

The explained variable GTFP is the calculation results based on DDF-BML index, δ_i , η_t and μ_{it} represent individual fixed effect, time fixed effect and random error term,

respectively. Meanings and processes of other variables are shown in Table 2.

3.2. Sample selection and data sources

3.2.1. Index selection of DDF-BML index

The selected input and output index should objectively reflect the actual situation of environmental performance of the iron and steel industry. Regarding the existing research, based on the rationality and availability of data, the following indicators are selected to measure the gtfp of iron and steel enterprises. The description and process of each index are presented in detail in Table 1.

Table 1. Input and Output Index of GTFP Measurement of Iron and Steel Enterprises

First-level index	Second-level index	Third-level index	Description
Input Index	Labor input	Number of employees	Number of employees in the enterprise
	Capital input	Net value of fixed assets	Original cost- depreciation of fixed assets
Output index	Expected output	Main business income	Income of the main business of iron and steel enterprises
	Non-expected output	Nitrogen oxide emission	Important pollutants with toxic side effects in the iron and steel industry
		Sulfur dioxide emission	Important pollutants with toxic side effects in the iron and steel industry

3.2.2. Variable selection of measurement model

Table 2. Influencing Factors of GTFP in Iron and Steel enterprises

Category	Second-level index	Name	Description
Explained variable		Green total factor productivity (GTFP)	DDF-BML measurement results
Explanatory variable	Micro enterprise factor	Enterprise R&D investment (RD)	R&D investment / main business income
		Asset-liability ratio (Lev)	Enterprise debt level
		Enterprise size (Scale)	Total number of employees
	Micro economic factor	Regional economic development level (GDP)	GDP of the province of the registration place
		Regional industrial structure (IS)	Proportion of added value of the tertiary industry in GDP
		Intensity of regional environmental regulation (ER)	Regional environmental protection fiscal expenditure / regional general budget fiscal expenditure

The data of iron and steel enterprises used in this paper are all from the CSMAR database, and the data of macroeconomic characteristic variables are from the National Bureau of Statistics.

4. Empirical Result Analysis

4.1. Analysis of DDF-BML results

In this paper, STATA16 is used to measure the change rate of gtfp of iron and steel enterprises, and the measurement results are reported in Table 3. As can be seen from Table 3, in general, the overall change rate of gtfp of iron and steel enterprises is not ideal. From 2016 to 2019, the average growth

rate was only 6.72%, lower than the average level of the manufacturing industry, falling behind at the end of the manufacturing industry [14]. Furthermore, we decomposed the change rate of gtfp into the change rate of technical efficiency (TECH) and technological progress (TECCH), and the average growth rates of the two were 2.32% and 4.29%, respectively. It can be found that the low growth rate of technical efficiency is the key constraint of the growth of gtfp in iron and steel enterprises. However, 1/3 of the samples presented the situation of technological regression, indicating that the change in technological level of iron and steel enterprises showed a fluctuating trend, and the continuous growth of gtfp cannot be separated from the continuous improvement of technological level.

Table 3. Change Rate of GTFP of Iron and Steel Enterprises from 2016 to 2019

Enterprise	Year	TFPCH	TECH	TECCH
Sangang Minguang Co, Ltd.	2017	1.9793	1	1.9793
Sangang Minguang Co, Ltd.	2019	1	1	1
CITIC Pacific Special Steel Group Co, Ltd.	2019	1	1	1
Bayi Steel Co, Ltd.	2017	0.8459	0.5485	1.5421
Bayi Steel Co, Ltd.	2018	1.8231	1.8231	1
Bayi Steel Co, Ltd.	2019	0.7497	1	0.7497
Ling Yuan Iron & Steel Co, Ltd.	2019	1.0333	0.9906	1.0431
Baogang United Steel Co, Ltd.	2018	0.9585	0.5627	1.7036
Baogang United Steel Co, Ltd.	2019	1.0005	1.7773	0.5629
Nanjing Iron & Steel United Co, Ltd.	2016	1.114	1	1.114
Nanjing Iron & Steel United Co, Ltd.	2017	1.9299	1	1.9299
Nanjing Iron & Steel United Co, Ltd.	2018	1.0242	1	1.0242
Shanxi Taigang Stainless Steel Co, Ltd.	2017	1	1	1
Shanxi Taigang Stainless Steel Co, Ltd.	2019	0.791	1	0.791
Anyang Iron & Steel Group Co, Ltd.	2019	0.9849	1.05	0.938
Fushan Special Steel Co, Ltd.	2018	0.9647	1.127	0.8559
Xinyu Iron & Steel Co, Ltd.	2018	1.1859	1.8853	0.629
Xinyu Iron & Steel Co, Ltd.	2019	1.0582	1	1.0582
Ben Gang Steel Plates Co, Ltd.	2018	0.9963	1.2643	0.788
Ben Gang Steel Plates Co, Ltd.	2019	1.0144	0.9637	1.0526
Liuzhou Steel Group Co, Ltd.	2017	1	1	1
Liuzhou Steel Group Co, Ltd.	2018	1.1735	1	1.1735
Liuzhou Steel Group Co, Ltd.	2019	1	1	1
Yongxing Materials Co, Ltd.	2019	1	1	1
Jiugang Hongxing Co, Ltd.	2017	1.0232	0.5244	1.9513
Jiugang Hongxing Co, Ltd.	2018	0.9995	1.1219	0.8909
Jiugang Hongxing Co, Ltd.	2019	1.07	1.6999	0.6295
Angang Steel Co, Ltd.	2017	1.1343	0.6084	1.8645
Angang Steel Co, Ltd.	2018	1.0161	1.2938	0.7853
Angang Steel Co, Ltd.	2019	0.9984	0.9404	1.0617

4.2. Analysis of econometric model results

Table 4. Regression Results of the Econometric Model

Variable Name	Fixed Effect Model
RD	-0.0184
	(-0.30)
LEV	-3.965
	(-1.64)
lnScale	-1.836***
	(-3.90)
lnGDP	3.824**
	(-2.23)
IS	-16.72
	(-1.20)
lnER	0.595
	(-0.87)
_cons	-10.1
	(-0.46)
N	30

Table 4 reports the calculation results based on Table 3. According to the results of regression, there is not enough evidence to show that R&D investment in iron and steel enterprises can affect its own gtfp, in other words, the growth of iron and steel enterprise R&D input cannot bring gtfp growth, which means the R&D investment in the iron and steel enterprises is invalid to a certain extent. The coefficient of LEV is negative, but not statistically significant, indicating that there is no correlation between enterprise asset-liability ratio and gtfp growth rate. The coefficient of the variable lnScale is significantly negative at the 1% level, indicating that with the expansion of the scale of iron and steel enterprises, the change rate of gtfp shows a downward trend. This means

that iron and steel enterprises as a whole are in a stage of scale diseconomy at present, and blind expansion of enterprises is not conducive to the growth of gtfp, which also indicates that further reform of the supply side of the iron and steel industry is imperative. At the macro level, the coefficient of variable lnGDP is positive and significantly different from zero at the level of 5%, showing that in regions with better economic development, the gtfp growth rate of enterprises is higher. However, the coefficient of variable IS is not significant, showing that regional industrial structure has no significant impact on the growth of gtfp of iron and steel enterprises. The coefficient of variable lnER is negative, but it is not statistically significant, indicating that the increase in regional environmental regulation intensity does not improve the gtfp of steel enterprises.

5. Conclusion and Suggestion

This paper systematically expounds the connotation of green production, measures the change rate of gtfp of listed iron and steel companies by using DDF-based two-stage Malmquist index, and analyzes its influencing factors from macro and micro perspectives. The main conclusions are as follows.

First, the overall gtfp growth rate of iron and steel enterprises is at the end of the manufacturing industry, and the task of green transformation is arduous. Second, the R&D investment of iron and steel enterprises has a limited effect on the growth rate of gtfp. The current R&D should focus on remedying key weaknesses, and put more emphasis on low-carbon production processes. Third, as China's iron and steel enterprises are in the stage of scale diseconomy, the unreasonable expansion of enterprise reduces the growth rate of gtfp, and the large-scale capacity agglomeration makes

environmental problems more prominent. Fourth, the level of economic development has a positive effect on the growth rate of gtfp.

Based on the above conclusions, the feasible path for realizing green production of the iron and steel enterprises is as follows.

5.1. Enterprise perspective

Firstly, as technology intensive enterprises, iron and steel enterprises should pay attention to improve technical efficiency, so that the input and output factors can achieve the optimal configuration and stimulate the green vitality of the iron and steel industry through the improvement of technical level. Secondly, besides resolving the defect in key steel material and realizing the independent guarantee of key materials, iron and steel enterprises should also constantly improve the low-carbon production process, enhance the new driving force, increase the proportion of electric furnace steel to make full use of scrap steel and promote the realization of the green production of iron and steel enterprises through the reform of production parameters. Finally, in terms of capacity utilization, on the one hand, iron and steel enterprises should eliminate backward capacity as soon as possible, completely eliminate capacity with high emission, high pollution and low efficiency. On the other hand, iron and steel enterprises should enhance planning capability and foresight, optimize industrial layout, do a good job of strategic planning to fully use the existing production base with less layout of new steel base projects.

5.2. Government perspective

First, the government should ensure the safety and stability of iron ore supply in the iron and steel industry. Second, the government should strengthen market-based capacity regulation mechanism and guide low-end capacity to exit the market. Third, strict law enforcement should be carried out on the steel industry to improve the relevant industry standard system and laws and regulations. Fourth, the government should guide the digital and intelligent development of the iron and steel industry, encourage steel enterprises to innovate their energy management models, establish a more efficient, clean and economical energy system, build a digital platform for carbon emissions from steel production, and boost the low-carbon development of the steel industry. Finally, the government should promote the establishment of collaborative optimization development mechanism in various industries, encourage the discussion of green production among industries, and promote the formation of multi-win multi-industry collaborative low-carbon development model.

References

- [1] Fan D, Sun X. Environmental Regulation, Green Technological Innovation and Green Economic Growth (in Chinese) [J]. *China Population Resources and Environment*, 2020, 30(06):105-115.
- [2] Ponikarova A S, Zotov M A, Salin A A. Management model of sustainable development of petrochemical industry enterprises [J]. *Journal of Physics: Conference Series*, 2020, 1679 (5): 052031 (8pp).
- [3] Zang J, Zhang X. Research on the High Quality Development Strategy of Green Economy in Fujian (in Chinese) [J]. *Science and Technology Management Research*, 2021, 41(05): 158-166.
- [4] Li Y. Research on Evaluating Green Development of Energy in China's Provinces and Regions: Take Henan Province as an Example [J]. *Science and Technology Management Research*, 2020, 40(19): 63-69.
- [5] Li Z, Zhou Y, Cai S, et al. Research on Influencing Factors of Regional Economic Green Growth under Carbon Emissions constraint[J]. *IOP Conference Series: Earth and Environmental Science*, 2020, 615(1):12-17.
- [6] Du K, Li J. Towards a green world: How do green technology innovations affect total-factor carbon productivity[J]. *Energy policy*, 2019, 131(8): 240-250.
- [7] Du Z, Sun R. Event Response of the Iron and Steel Industry to Environmental Regulation: Based on the Empirical Evidence of Chinese A-share Steel Enterprises (in Chinese) [J]. *Friends of Accounting*, 2021(12): 57-64.
- [8] Zheng H, Han T. Research on the Coupling Spatial Differentiation of Innovation System of Business Models in Iron and Steel Enterprises (in Chinese) [J]. *Contemporary Economic Management*, 2021, 43(05):1-9.
- [9] Gao Y, Xing Y, He F, et al. Research on Co-control Effectiveness Evaluation of Energy Saving and Emission Reduction Measures in China's Iron and Steel Industry (in Chinese) [J]. *Climate Change Research*, 2021, 17(04):1-14.
- [10] Nechifor V, Calzadilla A, Bleischwitz R, Winning M, et al. Steel in a circular economy: Global implications of a green shift in China[J]. *World Development*, 2020, 127.
- [11] Wang X, et al. Factor decomposition and decoupling analysis of air pollutant emissions in China's iron and steel industry[J]. *Environmental Science and Pollution Research*, 2020, 27(13): 15267-15277.
- [12] Liu H, Zhang Q, Zhang J, et al. Five-Year Plan of China's Iron and Steel Industry: Evolution and Adjustment Prospect -- Text Analysis of Planning Since the Tenth Five Year Plan (in Chinese) [J]. *Modernization of Management*, 2020, 40(03):29-35.
- [13] Li L. The Study of Green Total Factor Productivity and Influencing Factors of China's Industry (in Chinese) [D]. Jinan University,2012.
- [14] Shen W, Wu J, Ning Y, et al. Green Total Factor Productivity of Forest Products Industry in China: Panel Data Based on 31 Sectors of Manufacturing Industry (in Chinese) [J]. *Journal of Northwest Forestry University*, 2021, 36(04):1-8.