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Research on the Influence of the Coupling Coordination of the Logistics Industry and Manufacturing Industry on the Upgrading of the Manufacturing Industry

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ABSTRACT One of the objectives of coupling coordination between the logistics industry and manufacturing industry (hereinafter referred to as "two industries coordination") is to improve the competitiveness of the manufacturing industry. Using the slacks-based method (SBM) and coupling coordination degree model, the coupling coordination scheduling between the logistics industry and manufacturing industry is measured, and the coupling coordination measurement system of the logistics industry and manufacturing industry under low-carbon constraints is constructed. The DEA Malmquist model is used to measure the level of manufacturing upgrading, and a threshold regression model is used to study the mechanism of the two industries' coordination on manufacturing upgrading. The empirical study found that during 2009-2019, the average coordination of the two industries in the Yangtze River Delta was 0.64, which was basically in the stage of good coordination, and the coupling level showed a gradual upward trend. From 2009 to 2019, the average total factor productivity index of the manufacturing industry was 1.23, showing an upward trend. The coordination of the two industries can promote the upgrading of the manufacturing industry, and there is an obvious inverted U-shaped relationship. There is a double threshold for industrial scale and technological innovation. When the scale of the manufacturing industry is between 79.1 billion yuan and 97.4 billion yuan, the impact of industrial coupling coordination on the production efficiency of the manufacturing industry is greater. When the R&D expenditure is less than 9.89 billion yuan, the impact of industrial coupling coordination on the production efficiency of the manufacturing industry is greater. The study found that the larger the industrial scale of the manufacturing industry is, the more conducive it is to the coordination of the two industries, and the coupling coordination does not increase with the increase in R&D investment. The manufacturing industry is mainly light industry, so the proportion of optimal assets is relatively low under low-carbon constraints. The upper limit of optimal science and technology expenditure shows that there is the problem of excessive investment of optimal science and technology funds under low-carbon constraints.

INDEX TERMS Logistics industry and manufacturing industry, coupling coordination, carbon emissions, manufacturing upgrading.

I. INTRODUCTION

After more than 40 years of reform and opening up, especially after China's accession to the WTO in the 21st century, China's manufacturing industry has become the world's largest [1]. However, with the rise of protectionism in recent years, the security and resilience of the supply chain have been constantly challenged, which has brought many uncertain factors to the development of the manufacturing industry and made the unstable international environmental situation more severe. China's manufacturing industry itself is facing problems of low production efficiency, lack of

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innovation, overcapacity, unreasonable structure and so on. It is also facing the urgent task of realizing the goal of ''made in China 2025''. Therefore, China's manufacturing industry needs structural transformation, upgrading and optimization to eliminate existing difficulties [2]. It is gratifying that the interaction between the logistics industry and the manufacturing industry, as the economic adhesive, is causing them to form a closer relationship, and the coupling coordination of the two industries has become a new power engine to drive the upgrading of the manufacturing industry in the new era.

To implement the Chinese government's decision and deployment on promoting high-quality development, the implementation plan for promoting the deep integration, innovation and development of the logistics manufacturing industry was issued in 2020, which clearly puts forward this goal and promotes the transformation and upgrading of the manufacturing industry. Therefore, exploring the impact mechanism of the current coupling coordination of the logistics industry and manufacturing industry on the upgrading of the manufacturing industry is a positive response to national deployment and provides a reference for the high-quality development of the local logistics and manufacturing industries.

The coupling coordination effect of the logistics industry and manufacturing industry is reflected in the mutual coordination and cooperation of humans, equipment, capital, knowledge, skills and other resources to improve the overall operational efficiency and share risks to obtain synergistic benefits and continuously adapt to new changes in the external environment. The coupling and synergistic effects of the logistics industry and manufacturing industry include timeliness of information transmission, rapid market response, punctuality of goods handover, transfer of tacit knowledge, decline of logistics cost, enhancement of management flexibility, increase of revenue, and dispersion or reduction of risk. Therefore, on the one hand, at the operational level, the coupling coordination of the two industries promotes the upgrading of the manufacturing industry through changes in efficiency and the benefits of efficiency improvement brought by coordinated integrated service. On the other hand, at the level of industrial symbiosis, the two industries are coupled and coordinated. Through the new service mode and new business capabilities (such as the transmission of implicit knowledge) generated by cooperative enterprises in the symbiosis system, they create new values for the logistics industry and manufacturing industry and then promote the upgrading of the latter.

The Yangtze River Delta is an important gathering place for China's advanced manufacturing industry. At the forefront of China's reform and opening up, the Yangtze River Delta pays increasing attention to the interactive development of the service industry, especially the producer service industry and manufacturing industry, drives the transformation and upgrading of the manufacturing industry, improves the comprehensive competitiveness of the regional manufacturing industry, and effectively promotes the implementation of the national strategy of Yangtze River Delta integration. Research on the upgrading of the manufacturing industry in the Yangtze River Delta will help to strengthen the understanding of the growth quality and international status of China's manufacturing industry in the process of profound changes in the world pattern. One of the objectives of the coupling coordination between the logistics and manufacturing industries is to improve the competitiveness of the manufacturing industry. However, as a service industry attached to other industries, logistics service itself has the phenomenon of opposite benefits. The traditional extensive logistics development model has had difficulty meeting the needs of the manufacturing green supply chain. Under the 2030 and 2060 carbon peak carbon neutralization targets and under the constraints of low-carbon development of the logistics manufacturing industries, further study can evaluate whether these factors can effectively promote the upgrading of the manufacturing industry. Therefore, it is necessary to establish a more targeted theoretical framework measurement system under carbon constraints to analyze the impact of coupling coordination on industrial upgrading.

Therefore, to better understand the coupling coordination degree of logistics and manufacturing under carbon constraints, this study constructs a coupling coordination measurement system of logistics and manufacturing considering carbon emissions and uses the SBM method and coupling coordination degree model to analyze the coordination degree. The significant difference between this study and previous studies is that this study uses SBM to explore the performance of the industry, considering both expected output and unexpected output. Compared with the traditional DEA model, it can better understand performance under carbon constraints.

The potential academic contributions of this paper are as follows: (1) This study establishes a measurement system of coupling coordination between the logistics industry and manufacturing industry considering carbon emissions, and (2) this paper uses the threshold regression model to analyze the impact of the coupling coordination of the logistics industry and manufacturing industry on the upgrading of the manufacturing industry. The analysis has certain policy guidance and theoretical significance.

The remainder of this study is as follows. The second part reviews the relevant literature. The third part introduces the research methods. The fourth part constructs the index system and selects variables. The fifth part empirically studies the impact of coupling coordination on manufacturing upgrading. The sixth part gives the corresponding conclusions and suggestions for the future. The theoretical framework of coupling coordination and manufacturing upgrading is shown in FIGURE 1.

II. LITERATURE REVIEW

On the one hand, relevant scholars believe that the coordinated development of the logistics industry and manufacturing industry can promote their competitiveness.

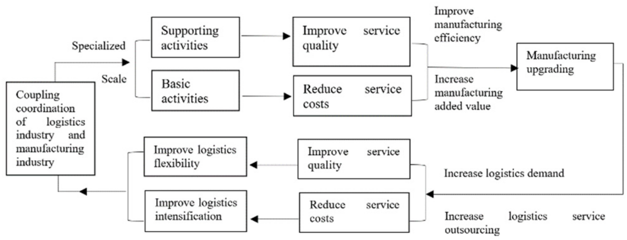

FIGURE 1. Theoretical framework of coupling coordination and manufacturing upgrading.

Yan [3] believes that the background of high-quality economic development requirements enriches the connotation of the sustainability of the logistics industry and puts forward new requirements for the high-quality development of the logistics industry. The coupling coordination degree between the logistics industry and high-quality economic development is generally not high. Su [4] believes that logistics plays a fundamental supporting role in facilitating the transformation and upgrading of traditional manufacturing industries. At the same time, the manufacturing industry forces the logistics industry to upgrade while providing a large number of logistics service needs. Chen [5] emphasizes that the linkage development of the manufacturing industry and logistics industry is an effective way to promote the transformation and upgrading of the manufacturing industry and strengthen the national real economy. However, the economic development level of each region is different, and the coupling coordinated development of the manufacturing industry and logistics industry is also different from region to region. Hongyan [6] believes that with the advancement of urbanization, the phenomenon of logistics industry agglomeration is becoming increasingly common. Based on the mechanism of the spatial characteristics and economic benefits of logistics industry agglomeration, this paper analyzes the impact of logistics industry agglomeration on industrial productivity and the spatial spillover effect by using the spatial Durbin model. The results show that, on different research scales, the spillover effect of logistics industry agglomeration on industrial productivity has significant differences, with a positive spillover effect at the national level and no significant spillover effect in the central region. Pinghong [7] believes that logistics services are a new driving force for the upgrading of the manufacturing industry in China's coastal areas. By improving the production efficiency, promoting the agglomeration, and expanding the market space of the manufacturing industry, we can upgrade this industry. Persson and Virum [8] believe that logistics services such as transportation and warehousing provided by the logistics industry are an important part of economic operations. At the same time, the logistics industry is facing the challenge of small-scale low-cost competitors and new large-scale foreign international network competitors. The establishment of an operation alliance between the logistics industry and manufacturing industry is an effective means to strengthen industry status and realize transformation and upgrading. Dirk [9] believes that the integration of the logistics industry and manufacturing industry is a future development prospect. The main task of the research on the integrated development of the logistics industry and manufacturing industry is to determine the content and mode of cooperation, and these industries can promote each other. Sohail [10] posits that the manufacturing industry is increasingly interested in the core competitiveness and capital savings brought by outsourcing activities. Through the comparative analysis of a questionnaire survey and an e-mail survey, it is concluded that on the one hand, the logistics industry can improve the production efficiency of manufacturing enterprises by improving the production flexibility of the manufacturing industry; on the other hand, it can also provide value-added services to improve the efficiency of the manufacturing industry. He [11] stressed that the linkage development of the manufacturing and logistics industries refer to the comprehensive integration of the manufacturing logistics business and the logistics business on the basis of the industrial relationship between the manufacturing and logistics industry. Then, the efficiency of the logistics industry is calculated by network DEA to describe the high-quality development of the logistics industry. Finally, He puts forward a manufacturing policy based on the "made in China 2025" strategy and tests its impact on the high-quality development of the logistics industry. Zimon [12] believes that the implementation of a standardized management system has a significant impact on improving supply chain management, and logistics operators can significantly improve many key supply chain management processes (including environmental and social performance) through the implementation of a standardized management system. Karia [13] identified five key resources of logistics service providers, namely, technical, physical, management expertise, relationship and organizational resources, all of which are positively related to customer service innovation and cost leadership of logistics service providers. Organizational resources are the most critical resources of logistics service providers. The results show that organizational resources can be bundled with particularly advanced technical resources to enhance customer innovation and with management expertise resources to enhance cost leadership.

Relevant scholars believe that the coordination measurement of the two industries should consider the impact of unexpected output, especially carbon emissions. Wen-Long [14] uses the nonexpected output SBM model to measure the linkage efficiency of logistics, manufacturing and two industries in the three provinces of Northeast China from 2006 to 2016 and analyzes the environmental factors that affect the linkage efficiency by using Tobit regression. The results show that the two industries in the three provinces in Northeast China are developing steadily, but the efficiency of the two industries is still not high. The main reason for the decline in regional production efficiency is pollutant discharge. The redundancy of input factors is the main reason for the decline in logistics industry efficiency. The input of science and technology and opening up have positive effects on the efficiency of the two industries, while government consumption has a negative impact on the efficiency of the two industries. Wang [15] range adjustment measurement model (RAM) is used to measure the efficiency of the logistics and manufacturing industries. The interaction mechanism between logistics efficiency and manufacturing efficiency is analyzed by using the p-var model. The results show that the interaction between logistics and manufacturing efficiency is unequal in different economic development fields. The interaction between logistics and manufacturing is completely different under different linkage modes, and the direction and intensity of influence are also completely different. Wen-Long [16] constructed a parallel network measurement system based on a super efficiency SBM model considering heterogeneity and unexpected output. The environmental performance of logistics and manufacturing industry coupling coordination was evaluated. The spatial and temporal characteristics of the development efficiency of the industrial linkage between the Northeast and the Yangtze River Delta from 2006 to 2016 were studied and compared by using the exploratory spatial data analysis method. The results show that the two-industry linkage in Northeast China has been evolving from the middle linkage stage to the weak linkage stage, and the Yangtze River Delta region shows continuous evolution from the Chinese Federation to the strong linkage stage. Gong [17] uses the three-stage super efficiency SBM model to measure the coordinated development level of logistics and manufacturing industries in 11 provinces and cities of the Yangtze River Economic Belt. The research finds that the overall coordination level between the two industries is in the limited coordination stage, and environmental factors affect the input efficiency of logistics and manufacturing industries. He [18], from the perspective of the logistics industry as a whole, selected 12 dimensions to build a comprehensive evaluation system of low-carbon logistics with 42 indicators. This paper establishes a general performance management system to evaluate the performance of logistics enterprises under the background of low-carbon and sustainable development and puts forward the main obstacles and strategies for the development of low-carbon logistics. Chen [19] examined the impact of production efficiency, carbon emissions reduction efficiency and market power structure on the realization of low-carbon manufacturing. The study found that under the balanced power structure, for two competitive manufacturers with different carbon emissions reduction efficiencies, higher carbon emissions reduction efficiency will enable manufacturers to produce more products, invest more green technologies and obtain more low-carbon products. Strong price and emission competition enables manufacturers to set higher unit retail prices and lower unit carbon emissions.

In addition to the carbon emissions of logistics and manufacturing, research on carbon emissions reduction in the construction industry has also attracted more attention. Zhang [20] believes that commercial buildings have great decarbonization potential. He studied the carbon emissions reduction efficiency of commercial buildings in China and the United States from 2001 to 2018 and found that the key to reducing carbon dioxide emissions of commercial buildings in the two countries is different, and China's carbon dioxide emission reduction efficiency is 1.1-1.9 times that of the United States. Li [21] believes that increasing energy consumption in the operation of commercial buildings is not conducive to China's carbon emissions reduction. The carbon emissions reduction changes in commercial building operations in 30 provinces in China from 2001 to 2016 were evaluated. It was found that the carbon intensity of commercial building operations in China increased by 2.88% annually during the study period, and the carbon emissions reduction efficiency in Southwest China was the highest. Chen [22] investigated the different emission scales of carbon emissions from residential and commercial building operations in 30 provinces of China through the carbon Kuznets curve (CKC) model. The study found that more than 90% of the samples were suitable for inverted U-shaped CKC. Zhang [23] believes that the construction industry represents the "last kilometer" plate in the transition to carbon neutrality. Taking Chinese commercial buildings as an example, this study makes an extensive data analysis on the road map of gradual carbon neutralization of building operation through the analysis of dynamic emission scenarios for the first time. The carbon emissions of commercial building operations will reach a peak in 2039 ($\pm$ 5), and emission factors and energy intensity are the main factors affecting the carbon peak.

On the one hand, the existing literature proves that the development of the logistics industry plays a positive role in the development of the economy and manufacturing industry from a macro perspective. Several scholars have proved through questionnaire surveys that the development of the logistics industry promotes the development of the manufacturing industry from a micro perspective. On the other hand, considering the unexpected output of the logistics industry and manufacturing industry, the carbon emissions of various industries have increasingly become the focus of scholars in recent years.

However, as mentioned above, current research focuses on the coordination measurement of the logistics industry and manufacturing industry under the traditional development mode. A few studies only consider the carbon emissions of a single industry and fail to solve the coordination measurement of the logistics industry and manufacturing industry under low-carbon constraints. One of the purposes of the coordinated development of the logistics industry and manufacturing industry is to improve the competitiveness of the manufacturing industry, but most scholars' research is limited to the coordination of the two industries. There is insufficient research on the impact of the coordination of the two industries on the upgrading of the manufacturing industry and coupling coordination under low-carbon constraints.

Low-carbon coupling coordination between the logistics industry and manufacturing industry is an organization that organically combines economic benefits, social benefits and ecological benefits under strict carbon emission constraints. Therefore, this paper constructs a low-carbon coupling and collaborative industrial development system from the perspective of carbon constraints and studies its nonlinear promotion effect on the upgrading process of the manufacturing industry, which has important theoretical and practical significance.

III. RESEARCH METHOD

A. COUPLING COORDINATION MODEL

1) COUPLING COORDINATION MODEL OF THE LOGISTICS INDUSTRY AND MANUFACTURING INDUSTRY

Coupling degree indicates the degree of mutual influence between two or more systems or elements due to interaction. The coupling coordination degree is the horizontal embodiment of mutual promotion and benign interaction between systems. In recent years, the theory of coupling coordination has been widely used in many fields of transportation, such as control operation strategy [24], planning strategy [25], predictive control and so on [26]. In the composite system composed of the logistics industry and manufacturing industry, the coordinated development of two industries refers to the evolution of two subsystems and their components in a harmonious and consistent direction, and the coupling of two industries refers to the mutual influence and interaction between two subsystems and their components. The order parameters in the two-industry complex system are the fundamental variables that determine the evolution trend of the system. The key to the evolution of the two-industry complex system is the synergy between the internal order parameters, and the coupling coordination degree is the measure reflecting that synergy.

$$C = 2\left\{(U_1 \cdot U_2) / (U_1 + U_2)^2\right\}^{1/2} \tag{1}$$

where C represents the coupling degree and U_1 and U_2 represent the comprehensive order parameters of logistics and manufacturing, respectively, expressed by logistics efficiency and manufacturing efficiency under low-carbon constraints.

The coupling degree C cannot reflect the overall level of logistics efficiency and manufacturing efficiency and the synergy between them. For example, when the logistics efficiency and manufacturing efficiency are very low, the coupling degree will be very high. Therefore, based on relevant research results, a coupling coordination degree model is constructed:

$$D = \sqrt{C \cdot T}, \quad T = \alpha U_1 + \beta U_2 \tag{2}$$

where D represents the coupling coordination degree; C represents the coupling degree; T represents the comprehensive coordination index of logistics efficiency and manufacturing efficiency under low-carbon constraints; and α and β are undetermined parameters and are assigned 0.5 according to the practices of most scholars. The coupling coordination degree is between 0 and 1, and the median segmentation method is adopted to divide the coupling coordination degree into five grades (Table 1). As shown in Table 1, the smaller the value of coupling coordination degree D is, the lower the coordination level between the logistics industry and manufacturing industry, and vice versa.

TABLE 1. Hierarchical division of coupling coordination degree.

Severe disorder	Moderate disorder	Slight coordination	Good coordination	High coordination
$0< D \le 0.2$	$0.2< D \le 0.4$	$0.4< D \le 0.6$	$0.6< D \le 0.8$	$0.8< D \le 1$

2) MEASUREMENT METHOD OF THE ORDER PARAMETER

To give consideration to the generality and rationality of the index system, this paper selects comprehensive technical efficiency as the decision-making basis for evaluating the comprehensive order parameters of the logistics industry and manufacturing industry.

In view of the heterogeneity of production technology in the Yangtze River Delta, this paper uses the common frontier model based on the SBM method to measure the comprehensive technical efficiency of the manufacturing and logistics industries. The calculation is realized with MaxDEA ultra7.0 software.

B. DEA MALMQUIST MODEL OF TOTAL FACTOR PRODUCTIVITY INDEX

Caves and other scholars first used the Malmquist index method to measure productivity change in 1982 [27]. By improving the DEA method, Fare established a nonparametric linear programming measurement algorithm to investigate the Malmquist productivity index of total factor productivity growth in two different periods [28]. The DEA Malmquist index method does not need to set the function form, assume the technical efficiency of the technical object, and does not need strict behavior assumptions. It has become a widely used method for measuring efficiency in nonparametric DEA methods.

First, the Malmquist productivity index M (x^{t+1}, y^{t+1}, x^t, y^t) from t to t+1 is constructed to measure the relationship between technological efficiency change, technological change and total factor change.

$$M\left(x^{t+1}, y^{t+1}, x^t, y^t\right) = \left[\frac{D^t\left(x^{t+1}, y^{t+1}\right)}{D^t\left(x^t, y^t\right)} \times \frac{D^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_{\mathrm{i}}^{t+1}\left(x^t, y^t\right)}\right]^{1/2} \tag{3}$$

where D^t (x^{t+1}, y^{t+1}) and D t (x^t, y^t) refer to the technology in period t, and t and t+1 are distance functions of DMUs. According to the Malmquist productivity index, it can be divided into technical efficiency change (effch) and technical change (techch). Technical efficiency change can be decomposed into pure technical efficiency change (Pech) and scale efficiency change (sech), and Equation (3) is decomposed into:

$$\begin{aligned} M\left(x^{t+1}, y^{t+1}, x^t, y^t\right) &= \frac{D^{t+1}\left(x^{t+1}, y^{t+1}|VRS\right)}{D^t\left(x^t, y^t|VRS\right)} \\ &\times \left[\frac{D^{t+1}\left(x^{t+1}, y^{t+1}|CRS\right)}{D^{t+1}\left(x^{t+1}, y^{t+1}|VRS\right)} \cdot \frac{D^t\left(x^t, y^t|CRS\right)}{D^t\left(x^t, y^t|VRS\right)}\right] \\ &\times \left[\frac{D^t\left(x^{t+1}, y^{t+1}\right)}{D^{t+1}\left(x^{t+1}, y^{t+1}\right)} \cdot \frac{D^t\left(x^t, y^t\right)}{D^{t+1}\left(x^t, y^t\right)}\right]^{1/2} \end{aligned} \tag{4}$$

wherewhen M $(x^{t+1}, y^{t+1}, x^t, y^t) > 1$, it means that the productivity level is improved, otherwise it is the opposite; Techch represents the technical change index from t to t + 1, Techch > 1 indicates technological progress, otherwise it is the opposite; Effch represents the technical efficiency change index from t to t +1, Effch > 1 means that the distance between t +1 phase and t +1 front is closer than that between t phase and t phase, and the relative efficiency is improved, otherwise it is the opposite; Pech > 1 means that the efficiency has been improved, and vice versa; Sech > 1 indicates that it is close to the optimal scale in the long run, and vice versa.

C. THRESHOLD REGRESSION MODEL

The threshold regression model was first proposed by Tong (1978) [29] and then further extended by Hansen *et al.* [30]. The core idea is to capture the critical point or critical region where the threshold variable may jump, where the model coefficient changes, which can better explain some real economic phenomena. According to the existing research results, there may be a nonlinear relationship between the two industries' coordination and the upgrading of the manufacturing industry, which has a certain interval effect. Therefore, this paper uses the threshold model for further investigation.

$$\begin{aligned} \mathrm{Eff}_{it} = \mu_i + \delta_1 \mathrm{D}_{it} + \beta_1 \mathrm{If}\alpha_{it} + \beta_2 \mathrm{Hum}_{it} + \beta_3 \mathrm{Tra}_{it} \\ + \beta_4 \mathrm{Pol}_{it} + \beta_5 \mathrm{Tdd}_{it} + \varepsilon_{it} \end{aligned} \tag{5}$$

If there is a single threshold effect, the model is as follows:

$$\begin{aligned} \mathrm{Eff}_{it} = \mu_i + \delta_1 \mathrm{D}_{it} \mathrm{I}(q_{it} \le \gamma) + \delta_2 \mathrm{D}_{it} \mathrm{I}(q_{it} > \gamma) + \beta_1 \mathrm{If}\alpha_{it} \\ + \beta_2 \mathrm{Hum}_{it} + \beta_3 \mathrm{Tra}_{it} + \beta_4 \mathrm{Pol}_{it} + \beta_5 \mathrm{Tdd}_{it} + \varepsilon_{it} \end{aligned} \tag{6}$$

In the case of the double threshold model, the model is as follows:

$$\begin{aligned} \mathrm{Eff}_{it} = \mu_i + \delta_1 \mathrm{D}_{it} \mathrm{I}(q_{it} \le \gamma_1) + \delta_2 \mathrm{D}_{it} \mathrm{I}(\gamma_1 < q_{it} \le \gamma_2) \\ + \delta_3 \mathrm{D}_{it} \mathrm{I}(q_{it} > \gamma_2) + \beta_1 \mathrm{If}\alpha_{it} + \beta_2 \mathrm{Hum}_{it} + \beta_3 \mathrm{Tra}_{it} \\ + \beta_4 \mathrm{Pol}_{it} + \beta_5 \mathrm{Tdd}_{it} + \mu_i + \varepsilon_{it} \end{aligned} \tag{7}$$

In the formula, the explained variable is the total factor productivity (EFF) to measure the upgrading status of the manufacturing industry, the main explanatory variable is the coupling coordination degree (D) to measure the coupling coordination of the logistics industry and manufacturing industry, I (∗) is the indicator function, q is the threshold variable, and γ is the specific threshold value. At the same time, to improve the robustness of the econometric model, other factors that may affect the upgrading effect of the manufacturing industry are added, including five control variables: fixed asset investment (IFA), human capital (HUM), international trade (TRA), industrial policy (POL), and traffic development degree (TDD). μ_i is the industry individual effect, ε_{it} is the random disturbance term, and $\varepsilon_{it} \sim \mathrm{iidN}(o, \delta^2)$.

IV. SELECTION OF INDICATORS AND VARIABLES

A. INDICATOR SELECTION

1) INDICATOR SYSTEM OF THE ORDER PARAMETER IN THE COUPLING COORDINATION MODEL

Combined with some selection principles (scientificalness, practicability, data availability, isotropy, among others) of the indicator system, the efficiency evaluation index of the coupling coordination of the manufacturing and logistics industries is constructed from the perspective of input and output. The data used in the study mainly come from the Statistical Yearbook of Shanghai, Jiangsu Province and Zhejiang Province in the Yangtze River Delta and the statistical database of the China Economic Network (Urban Yearbook database). The specific selection indicators are shown in Table 2; the input–output system in Table 2 considers not only the expected output of the manufacturing system and logistics system but also the unexpected output, that is, the constraint of carbon emissions.

This paper takes the CO_2 emissions of the logistics industry and manufacturing industry as the unexpected output index. Referring the research of Xu [31] and Shiqing [32] on carbon emissions from logistics and manufacturing. first, the primary energy consumption of 21 fuels mainly consumed by logistics and manufacturing industries, such as raw coal, diesel, kerosene, gasoline, fuel oil, liquefied petroleum and natural gas, is selected and converted into standard coal as the total energy source consumption of the two industries. Then, the above seven energy consumptions are converted according to the carbon emission coefficient in the guidelines for national greenhouse gas emission inventories of the Climate Change Commission (IPCC), and the CO_2 emissions of the logistics industry and manufacturing industry are obtained. The calculation formula is:

$$CO_2 = \sum_{i=1}^{n} E_i \times CF_i \times CC_i \times COF_i \times \frac{44}{12} \tag{8}$$

where i is the type of fuel, E_i is the consumption of i fuels, CF_i is the calorific value of i fuels, CC_i is the carbon content of i fuels, and COF_i is the oxidation factor of the fuel [33].

TABLE 2. Indicator system of order parameter of the logistics industry and manufacturing industry coupling coordination evaluation.

Evaluation system	Pointer type	Name of index	Unit
Manufacturing system	Input indicators	The number of employees on the job in the manufacturing industry	Ten thousand people
		Total assets of industrial enterprises above designated size	100 million
	Output indicators	industrial added value	100 million
		Main business income of industrial enterprises above designated size	100 million
	Unexpected output	Carbon Emissions from Manufacturing	Tons
Logistics system	Input indicators	Number of employees in the logistics industry	Ten thousand people
		Fixed capital investment	100 million
		energy consumption	Ten thousand tons of standard coal
	Output indicators	highway freight volume	Tons
		GDP of logistics industry	100 million
		Cargo turnover	Million ton-km
	Unexpected output	Carbon Emissions from Transportation	Tons

2) INDICATOR SELECTION OF THE MANUFACTURING UPGRADING INDEX

Based on the Malmquist index of Xuefeng *et al.* [34], Chunbin and Renfa [35], the total factor production efficiency is measured. According to the basic requirements of the DEA theory, 25 cities in the Yangtze River Delta region are selected as the basic production units, and the industrial sales output value (100 million yuan) of manufacturing enterprises above scale is selected. The net value of fixed assets (100 million yuan) and the average number of employees (10000 people) are used as input–output indicators. The data are as follows:

1. Input index 1: the net value of fixed assets of manufacturing enterprises above the designated size in the China Industrial Statistical Yearbook is selected as the first input index. Since the data are net values, there is no need to conduct depreciation treatment. It is only necessary to reduce the fixed assets investment price index to the constant price index based on 2009.

2. Input index 2: The second input index is the average number of workers employed by manufacturing enterprises above the designated size in the China Industrial Statistical Yearbook.

3. Output index: the output value of industrial sales of manufacturing enterprises above the designated size in the China Industrial Statistical Yearbook is selected as the output index, and all data are obtained after adjustment according to the industrial producer price index with 2009 as the base period.

B. VARIABLE SELECTION OF THE THRESHOLD REGRESSION MODEL

1) EXPLAINED VARIABLE

For the selection of manufacturing upgrading indicators, scholars use total factor production efficiency Hong and Naihua [36]. The DEA Malmquist model in the previous section is used to measure the total factor production efficiency (EFF) of the manufacturing industry from 2009 to 2019 under a fixed parameter ratio.

2) MAIN EXPLANATORY VARIABLE

This paper selects the coupling coordination degree of the logistics industry and manufacturing industry to measure the coupling coordination level of the two industries and uses it as the main explanatory variable.

3) THRESHOLD VARIABLE

Industrial scale (ISV). An appropriate industrial scale is an important factor affecting industrial upgrading [37]. An excessive scale will lead to a waste of resources and overcapacity; if the scale is too small, it is not easy to form a competitive advantage and scale effect. As the industrial sales output value not only includes the total output of industrial products but also reflects the input level of production factors, this paper selects this indicator to measure the industrial scale of the manufacturing industry.

Technological innovation (TI). First, by increasing R&D investment, enterprises can optimize resource allocation efficiency and promote technological innovation, thus driving industrial upgrading. Second, after the realization of technological innovation, enterprises can give full play to the effect of technology transfer through the interaction of information and knowledge and further accelerate the upgrading of the manufacturing industry [38]. This paper selects regional

R&D internal expenditure to measure the level of technological innovation.

4) CONTROL VARIABLES

Investment in fixed assets (IFA). Most of China's large-scale manufacturing industries are state-owned enterprises. The government's investment intensity and investment decisions determine and affect the development direction of manufacturing enterprises to a large extent, especially in economically underdeveloped areas. The upgrading of the manufacturing industry is still highly dependent on investment in fixed assets [39]. Therefore, this paper selects the proportion of fixed asset investment in the manufacturing industry in the whole society to measure.

Human capital (HUM). On the one hand, workers improve their professional skills and comprehensive quality through education, training and practice, which leads to the upward flow of human capital and related factors, driving the upgrading of the manufacturing industry from the low end to the high end. On the other hand, the accumulation of human capital also acts on the income and consumption of workers, leading to the upgrading of consumer demand, which drives the transformation and upgrading of the manufacturing industry again. Referring to the calculation method of Peng Guohua (2005), this paper takes the stock of human capital Hit = $\exp(\ln h_{it})$*Litas as the measurement index, where h is the regional per capita human capital and l is the total amount of regional employment [40].

International Trade (TRA). Since the reform and opening up, China's manufacturing industry has made great progress due to the rapid growth of foreign trade, which has played an important role in the scale growth and competitiveness improvement of the manufacturing industry and boosted the upgrading of the manufacturing industry [41]. Because both import and export and foreign direct investment will have an impact on the upgrading effect of the manufacturing industry, this paper selects the arithmetic mean value of the two to measure international trade, that is, trade = (total import and export/GDP + total FDI/GDP)/2.

Industrial policy (POL). Local governments can have a positive impact on the upgrading of the manufacturing industry through targeted measures such as talent introduction, taxation, investment and financing, and information sharing [42]. Therefore, this paper selects the proportion of local fiscal expenditure in GDP to express the effect of industrial policy.

Traffic development degree (TDD). The developed degree of traffic can promote the flow efficiency of factors and goods and reduce the transaction cost of manufacturing enterprises in time and space. The interconnected developed transportation network can promote the spatial agglomeration of industries and then produce a scale effect, leading to the improvement of manufacturing competitiveness and labor productivity, which has an important impact on the industrial upgrading of the manufacturing industry [43]. To describe the effect of infrastructure construction on the upgrading of the manufacturing industry, this paper selects the per capita freight volume to measure.

The data corresponding to the indicators selected in this paper are mainly from the 2009-2019 China Urban Statistical yearbook. In the process of data selection and processing, each value index is adjusted to the data based on 2009 through the price index. To eliminate the influence of heteroscedasticity and time trends, absolute variables such as industrial scale, technological innovation, human capital and transportation development degree are logarithmized, and other logarithmic variables are no longer treated. The descriptive statistical results of the selected indicators are shown in Table 3. According to the data obtained, we use Stata 12 software for empirical analysis.

TABLE 3. Descriptive statistics of variables.

Variable	Number of samples	average value	standard deviation	minimum value	Maximum
Total factor productivity	275	1.047	0.247	0.371	2.011
D	275	0.332	0.045	0.143	0.782
ISV	275	8.873	1.15	5.379	11.429
TI	275	2.388	1.337	1.386	6.103
IFA	275	0.101	0.011	0.016	0.411
HUM	275	9.126	0.874	5.837	10.556
TRA	275	0.086	0.114	0.011	0.822
POL	275	0.127	0.007	0.05	0.57
TDD	275	3.026	0.417	1.734	4.249

Note: The data are from the Statistical Yearbook over the years. After the model calculation, the results are sorted out by the author.

V. EMPIRICAL ANALYSIS

A. EMPIRICAL RESULTS OF COUPLING COORDINATION

As seen from Table 4, during the investigation period, the average value of the coupling coordination of the logistics industry and manufacturing industry in the Yangtze River

TABLE 4. Calculation results of the coupling coordination degree between the logistics industry and manufacturing industry.

2009 (0.48)	2010 (0.50)	2011 (0.53)	2012 (0.57)	2013 (0.58)	2014 (0.66)
2015 (0.68)	2016 (0.71)	2017 (0.75)	2018 (0.78)	2019 (0.84)	mean value (0.64)

Delta was 0.64. The logistics industry and manufacturing industry were basically in the good coordination stage, and the coupling level showed a gradual upward trend. This shows that as the most active region in China's economy, the coordinated development level of the logistics industry and manufacturing industry in the Yangtze River Delta is in a high development stage.

B. EMPIRICAL RESULTS OF MANUFACTURING UPGRADING

As seen from Table 5, on the whole, the average Mi index of 2009-2019 is 1.23 > 1, up 23%, indicating that the total factor productivity of the manufacturing industry in 2009-2019 is on the rise as a whole. From each year, the MI index of 2009-2019 is greater than 1, and the total factor productivity shows a growth state. The MI index of 2013-2014 is the highest, which is 1.91, an increase of 91%. The reason may be that in response to the economic crisis in 2012, the state launched a $4 trillion economic stimulus plan, which played a strong role in driving the development of the manufacturing industry in the next period from 2013 to 2014. This shows that MI continues to rise in most of the study areas, which indicates that the manufacturing efficiency of the study area is increasing year by year.

TABLE 5. Total factor productivity change index of the manufacturing industry in the yangtze river delta region from 2009 to 2019 and its mean decomposition value.

Time	MI	EC	TC	PEC	SEC
2009-2010	1.33	1.17	1.14	0.98	1.20
2010-2011	1.26	1.13	1.12	1.00	1.13
2011-2012	1.02	0.99	1.03	1.08	0.93
2012-2013	1.26	1.22	1.05	0.94	1.41
2013-2014	1.91	2.00	0.99	1.11	1.84
2014-2015	1.14	1.15	1.00	1.07	1.08
2015-2016	1.10	1.09	1.02	1.00	1.09
2016-2017	1.13	1.11	1.02	0.96	1.16
2017-2018	1.05	1.04	1.01	0.98	1.07
2018-2019	1.11	1.07	1.07	0.94	1.15
mean value	1.23	1.20	1.04	1.01	1.21

From the perspective of the decomposition of the manufacturing upgrading index, it is found that, on the one hand, the rise of manufacturing TFP is mainly caused by the rise of the EC technical efficiency index. The results show that the scale effect, macro development environment and organization management level of the manufacturing industry in the Yangtze River Delta are high. On the other hand, although the exchange and cooperation between cities have been strengthened through the implementation of industrial preferential policies and the sharing of advanced technology and management concepts, the exchange and cooperation between cities have been strengthened by technology spillover and diffusion. However, the main factor supporting the development of the manufacturing industry in the Yangtze River Delta is the investment scale effect, and the contribution of technological progress to the production efficiency of various factors of the manufacturing industry is insufficient.

C. TEST RESULTS OF THE THRESHOLD EFFECT

The threshold effect is tested by two threshold variables: industrial scale and technological innovation. The results are shown in Table 6 and Table 7.

TABLE 6. Threshold effect test results of industrial scale as a threshold variable.

Number of threshold values	Sum of squares of residuals	Mean square error	F statistic	P value	10%	5%	1%
Single threshold	12.045	0.05	19.15	0.030	13.703	17.009	24.901
Double threshold	11.285	0.047	16.18	0.037	11.518	15.226	22.424
Triple threshold	10.447	0.043	19.25	0.603	15.847	21.697	58.206

1) TEST RESULTS OF THE THRESHOLD EFFECT OF INDUSTRIAL SCALE

First, the threshold effect test is carried out by taking the industrial scale as the threshold variable, and the results reject the original hypothesis, indicating the existence of a threshold effect. Then, double threshold and triple threshold tests are carried out, and the results are shown in Table 6. At the 5% level, there is a double threshold in the Yangtze River Delta.

2) TEST RESULTS OF THE THRESHOLD EFFECT OF TECHNOLOGICAL INNOVATION

Finally, the threshold effect test is carried out by taking technological innovation as a threshold variable, and the results reject the original hypothesis, indicating the existence of a threshold effect. Next, double threshold and triple threshold tests are carried out, and the results are shown in Table 7.

TABLE 7. Threshold effect test results of technological innovation as a threshold variable.

Number of threshold values	Sum of squares of residuals	Mean square error	F statistic	P value	10%	5%	1%
Single threshold	11.495	0.048	31.55	0.000	10.686	12.659	19.81
Double threshold	10.802	0.045	15.39	0.023	10.569	12.847	22.305
Triple threshold	10.536	0.044	6.06	0.680	17.555	22.797	29.685

At the 5% level, there is a double threshold in the Yangtze River Delta.

According to the threshold effect test, we find that there are double thresholds in the three threshold variables of the Yangtze River Delta, so we can further calculate the threshold value for threshold effect regression.

D. VARIABLE SELECTION OF THE THRESHOLD REGRESSION MODEL

According to the threshold effect test, it can be found that the two threshold variables of the group data are looking for the double threshold, so the threshold value can be further calculated for threshold effect regression. Through the threshold effect regression, the thresholds of the three threshold variables in the Yangtze River Delta are shown in Table 8 below.

TABLE 8. Estimation results of the threshold value.

Model	Threshold value	
	ISV	R&D
Single threshold	79.1 billion yuan	9.89 billion yuan
Double threshold	97.4 billion yuan	61.8 billion yuan

1) REGRESSION RESULTS OF THE THRESHOLD EFFECT OF INDUSTRIAL SCALE

As seen from Table 9, the coupling coordination of the two industries in the Yangtze River Delta has a significant positive role in promoting the upgrading of the manufacturing industry, and there is a significant inverted U-shaped relationship. With the continuous improvement of industrial scale in the manufacturing industry, the positive promoting effect of the coupling coordination of the two industries on the upgrading of the manufacturing industry decreased rapidly after reaching the peak.

TABLE 9. Regression results of industrial scale.

variable	coefficient	T value	P value
D（ISV≤79.1 billion yuan）	0.891***	3.64	0.0000
D（79.1 billion yuan < ISV≤97.4 billion yuan）	2.768***	7.22	0.0000
D（ISV >97.4 billion yuan）	0.715***	4.50	0.0000
IFA	0.5420	-1.41	0.1590
HUM	0.1580***	0.15	0.0880
TRA	-0.2571***	-0.93	0.0355
TDD	0.7111	1.24	0.2150
POL	0.1103***	1.92	0.0570
_cons	0.5982***	3.93	0.0000

According to the results of the control variables in Table 9, human capital and industrial policy have a significant role in promoting the upgrading of the manufacturing industry, and the factor with the greatest role is human capital. The reason may be that the upgrading of the manufacturing industry itself requires considerable investment in innovative resources, and the Yangtze River Delta, as the current gathering place of China's high-end talent, has inherent advantages. Moreover, as the phenomenon of ''Peacock Flying Southeast'' has intensified in recent years, the Yangtze River Delta has become increasingly attractive to high-end talent. International trade has a restraining effect on the upgrading of the manufacturing industry. The reason may be that trade, as the main carrier of technology spillover, not only drives the transformation and upgrading of the manufacturing industry but also brings great pressure to resources and the environment, increases the carbon emissions of the local manufacturing industry, and may become a ''pollution refuge'' for foreign enterprises [44]. Investment in fixed assets and traffic development have no significant impact on the upgrading of the manufacturing industry. The reason may be that the market economy in the Yangtze River Delta is developed, and the effect of fixed asset investment in the form of government investment has made it difficult to meet the needs of upgrading the local manufacturing industry at a high level. The local transportation infrastructure in the Yangtze River Delta is relatively perfect, and the promotion effect of transportation facilities can no longer meet the higher-level needs of local manufacturing upgrading.

TABLE 10. Regression results of technological innovation.

variable	coefficient	T value	P value
D（TI≤9.89 billion yuan）	1.730***	8.14	0.000
D（9.89 billion yuan < TI≤61.8 billion yuan）	0.847***	4.87	0.000
D（TI >61.8 billion yuan）	0.443***	2.75	0.006
IFA	0.9411	0.24	0.810
HUM	0.7277***	0.7	0.048
TRA	-0.1447***	-0.53	0.059
TDD	0.4016	0.75	0.456
POL	0.7229***	1.27	0.020
_cons	0.4208***	2.66	0.008

2) REGRESSION RESULTS OF THE THRESHOLD EFFECT OF TECHNOLOGICAL INNOVATION

As seen from Table 10, the coupling coordination of the two industries in the Yangtze River Delta has a significant positive role in promoting the upgrading of the manufacturing industry, and there is a significant inverted U-shaped relationship. With the continuous improvement of technological innovation in the manufacturing industry, the positive promoting effect of the coupling coordination of the two industries on the upgrading of the manufacturing industry decreased rapidly after reaching the peak.

According to the results of the control variables in Table 10, human capital and industrial policy have a significant role in promoting the upgrading of the manufacturing industry, and the factor with the greatest role is human capital. International trade has a restraining effect on the upgrading of the manufacturing industry. The results are consistent with the industrial scale.

The difference is that the industrial scale with the best effect on coupling coordination is not the maximum value but the intermediate value. The best R&D investment to promote coupling coordination is the minimum value.

VI. CONCLUSION AND SUGGESTIONS

First, this paper constructs a coupling coordination measurement system of logistics and manufacturing considering carbon emissions and measures the coupling coordination of logistics and manufacturing in the Yangtze River Delta. Then, based on the DEA Malmquist model, the total factor productivity change of manufacturing in the Yangtze River Delta is calculated, and the change is further decomposed. Finally, five control variables are selected: investment in fixed assets, human capital, international trade, industrial policy and traffic development. The threshold regression model is used to investigate the nonlinear influence of the coupling coordination of the logistics industry and manufacturing industry on the upgrading of the manufacturing industry under the threshold variables of different industrial scales and technological innovations. The main conclusions are summarized as follows:

(1) From 2009 to 2019, the average coupling coordination degree of the logistics industry and manufacturing industry was 0.64. It is basically in the stage of good coordination, and the coupling level in the Yangtze River Delta is gradually rising.

(2) The DEA Malmquist model is used to measure the change and decomposition of the manufacturing upgrading index.

From the overall evolution analysis, it is found that the total factor productivity of the manufacturing industry in the Yangtze River Delta region rose in 2009-2019.

From the perspective of the decomposition of the manufacturing upgrading index, it is found that the rise of manufacturing TFP is mainly caused by the rise of the EC technical efficiency index. However, the main factor supporting the development of the manufacturing industry in the Yangtze River Delta is the investment scale effect, and the contribution of technological progress to the production efficiency of various factors of the manufacturing industry is insufficient.

(3) The threshold regression model is used to measure the nonlinear influence of the coupling coordination of logistics and manufacturing on the upgrading of the manufacturing industry with industry scale and technological innovation as threshold variables. The results show that the coupling coordination of the two industries in the Yangtze River Delta plays a significant positive role in promoting the upgrading of the manufacturing industry, and there is an obvious inverted U-shaped relationship. The detailed analysis is as follows:

In the Yangtze River Delta, there are double thresholds for industrial scale and technological innovation. When the scale of the manufacturing industry is between 79.1 billion yuan and 97.4 billion yuan, the effect of industrial coupling coordination on the production efficiency of the manufacturing industry is stronger, and vice versa; it shows that a larger industrial scale of the manufacturing industry in the Yangtze River Delta is not more conducive to coupling coordination. When R&D expenditure is less than 9.89 billion yuan, the effect of industrial coupling coordination on the production efficiency of the manufacturing industry is stronger, and vice versa. This shows that the coupling coordination in the

Yangtze River Delta does not increase with the increase in R&D investment.

The results of the industrial scale threshold effect show that the proportion of assets is relatively low because the manufacturing industry in the Yangtze River Delta is dominated by light industry. The upper limit of the optimal science and technology expenditure in the Yangtze River Delta shows that there is a problem of excessive investment in science and technology funds. We should reasonably control the industrial scale of the manufacturing industry and should allocate funds and resources appropriately and pay attention to the output efficiency of science and technology funds.

It is worth noting that traditional research results without considering low-carbon constraints are compared and analyzed, which makes it clear that the results obtained question the current state of knowledge. For example, under low-carbon constraints, the larger the scale of manufacturing industry, the worse of coupling coordination. The reason may be that higher manufacturing agglomeration brings increased emission pressure, which is not conducive to the industrial development direction under current environmental regulations and is unfavorable to the coordinated development of low-carbon industry coupling. This view has also been reported by Sun [45]; the conclusions of this study are therefore supported.

Similarly, the traditional idea that higher R&D expenditure is better is worth further discussion. The reason may be that the manufacturing industry in the Yangtze River Delta is composed of high-tech industries and light industries. Because the high-tech industry has high technical barriers, the purpose of enterprise R&D activities is often to strengthen cutting-edge technological innovation, improve production efficiency, and then stabilize their core competitiveness. Therefore, the ''output effect'' caused by R&D investment exceeds the ''energy conservation and emissions reduction effect''. This kind of industry does not pay attention to energy conservation and emissions reduction, but the effect of R&D investment on energy conservation and emissions reduction is not obvious compared with that of research on cutting-edge science and technology. Therefore, the energy efficiency of the manufacturing industry with the attribute of local light industry has been at a high level, and the impact of R&D investment on carbon emissions is not significant Yong [46]. This leads to the low efficiency of R&D capital investment in industrial low-carbon coupling coordination.

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