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Interaction Mechanism Between the Logistics Industry and Manufacturing Industry–Based on the Perspective of Different Linkage Types

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ABSTRACT The logistics industry and manufacturing industry are naturally closely linked. Analysis of the interaction mechanism between the logistics industry and manufacturing industry based on two different linkage types of outsourcing logistics and self-owned logistics is helpful to deepen the understanding of the relationship between these two industries. This paper performs a comparative analysis of the different linkage modes represented by the three northeast provinces and the Yangtze River Delta region in China. First, this paper analyzes the interactive influence mechanism of the logistics industry efficiency and manufacturing industry efficiency. Second, the adjustment mechanism of the logistics industry to the manufacturing industry under the two modes is analyzed according to the different logistics organization modes of the manufacturing industry. Finally, we build an efficiency measurement model considering the joint efficiency of the economy and environment. Using the panel vector autoregression (PVAR) model, this paper empirically compares and analyzes the interaction between the logistics industry and manufacturing industry under different linkage modes. The results show the following: (1) In different economic development areas, the interaction between logistics and manufacturing efficiency is not equal. (2) According to the different logistics methods of the manufacturing industry, there are self-owned modes and logistics outsourcing modes in the linkage development of the logistics industry and manufacturing industry. There are great differences in the mode and degree of action between the two modes. (3) The interactive relationship between logistics industry and manufacturing industry under different linkage modes is totally different, and the direction and intensity of the impact are also completely different.

INDEX TERMS Logistics industry and manufacturing industry, interaction mechanism, different linkage types.

I. INTRODUCTION

There is a close relationship between the logistics industry and manufacturing industry, which is not temporary and exists in the long-term development process of the two industries. In addition, this close connection is in the whole game process of the two industries, which promotes the common development of the industry. The linkage between the logistics industry and manufacturing industry is a continuous and interactive dynamic process. It is a type of activity that combines the logistics operations of the manufacturing industry and the logistics industry based on their industrial association to promote the common development of both sides. The difference in the regional economic development level is directly reflected in the difference in the manufacturing development level. Therefore, the interactive relationship between logistics industry and manufacturing industry in different regions is not equal, and the interaction mode and degree between them are also quite different. The key to the common development of the manufacturing industry and logistics industry is to establish a relationship of mutual promotion, mutual benefit and interdependence [1]–[3]. Research on the interactive relationship between the logistics industry and manufacturing industry is helpful to determine the problems existing in

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the development of the linkage between the manufacturing industry and logistics industry and to explore ways to improve the efficiency of the linkage. This research will promote the transformation and upgrading of the manufacturing industry, promote the optimization and upgrading of the regional economic structure, and provide a new impetus for the revitalization of regional economies [4]–[6].

China has a vast territory and complete types and a wide distribution of the manufacturing industry. The development stage and mode of the manufacturing industry in different regions are quite different. The logistics organization mode of the manufacturing industry in different regions is also quite different. Therefore, the interaction between the manufacturing industry and logistics industry should be studied differently [7]–[10].

Due to the problems remaining from the government's historical regulation and the reform of state-owned enterprises, a large number of state-owned enterprises have emerged in the northeast old industrial base of China. There are many departments in these enterprises, and logistics services are generally provided by state-owned enterprises themselves. In contrast, in the southeastern coastal region of China, manufacturing enterprises in the Yangtze River Delta region introduced advanced foreign management experience and technology earlier due to their early participation in the process of reform and opening up, forming a pattern of numerous local third-party logistics companies providing logistics outsourcing services for manufacturing enterprises. To facilitate the comparative study, this paper is based on two methods that the manufacturing industry can use to obtain logistics services: internal supply-self-owned logistics and external supply-logistics outsourcing. These methods divide the linkage between the logistics industry and manufacturing industry into a self-owned logistics mode and a logistics outsourcing mode. The northeastern region, which is dominated by the state-owned self-operating mode, and the Yangtze River Delta region, which is dominated by logistics outsourcing services, are selected as the research objects.

The purpose of this study is to explore the interaction between the logistics industry and the efficiency of the manufacturing industry under different linkage modes, as well as the interaction between them, to improve the linkage development levels of the logistics industry and the manufacturing industry, reduce the logistics costs of the manufacturing industry, and facilitate the transformation and upgrading of the manufacturing industry. This study provides references for the managers of logistics and manufacturing industries and provides suggestions and insights for improving the efficiency of the logistics and manufacturing industries.

The potential academic contributions of this paper are as follows: (1) The research divides the linkage types of the logistics industry and manufacturing industry into two types and selects appropriate regions for empirical analysis. (2) This study establishes an RAM model considering the joint efficiency measurement of the economy and environment, which can not only eliminate the problems of ''angle'', ''radial'' and nonrelaxation variables existing in the traditional DEA model, but can also realize the joint measurement of economic efficiency and environmental efficiency. (3) This paper uses the PVAR model to analyze the interaction between the logistics industry and manufacturing industry under different linkage modes, and the comparative analysis is of theoretical significance.

The remainder of this study is as follows. The second section reviews the relevant literature. The third section introduces the theoretical hypothesis. The fourth section constructs the analysis model and empirically studies the interaction between the logistics industry and manufacturing industry under different linkage modes. The fifth section gives the corresponding conclusions and suggestions for the future.

II. LITERATURE REVIEW

Academic circles have performed a considerable amount of research in the field of logistics outsourcing, and the research results in this area are still increasing. Regarding the geographical scope of studies, there are many literatures on logistics outsourcing in developed countries or regions while there are relatively few literatures on developing countries, especially China. There are two different views on the impact of logistics outsourcing on enterprise performance. The first view is that logistics outsourcing has a positive impact on enterprise performance. For example, Sohail and Sohal (2003) conducted a survey on Malaysian enterprises and found that 3PL services have a positive impact on the costs, strategic performance and customer satisfaction of customer enterprises [11]. Sahay and Mohan (2006) constructed a research framework in which the input variables are enterprise characteristics, including the degree of utilization of third-party logistics and the causes and effects of logistics outsourcing [12]; and the output function is the utilization of third-party logistics services by enterprises in the future, which is affected by three input variables. Through the statistical analysis of the data obtained from their questionnaire survey, Sahay and Mohan found that although the third party logistics practice in India is still in the early stage of development, the use of third-party logistics services has a significant positive impact on enterprise performance. Rahman (2011) conducted a questionnaire survey of logistics operations managers of 210 large-scale enterprises in Australia and found that the use of third-party logistics has a positive impact on the performance of the internal logistics systems of Australian enterprises [13].

Some scholars believe that because the third-party logistics industry is still in the primary stage of development in China, most of China's manufacturing enterprises have to provide their customers with major logistics services (self-owned logistics). However, it must be recognized that compared with professional third-party logistics enterprises, manufacturing enterprises face many challenges in human resources, customer service and information technology integration [13]. Choi *et al.* (2016) believes that the coordination of the service supply chain requires an innovative business strategy and a new analysis mode, especially logistics services. The use of information is an important chain in service outsourcing supply. Outsourcing is a high risk activity. Service supply chain coordination and risk management are very important to logistics [14]. Shi *et al.* (2016) studied the emerging value-added services of third-party logistics. The paper proposes a real third-party purchase service model and then tests the conceptual model with a structural equation model based on the survey data of 3PL providers in China. The results show that uncertainty, order frequency and transaction size (rather than asset specificity) are significantly correlated with third-party service purchases [15].

The second view is that logistics outsourcing has no effect on enterprise performance. Hsiao *et al.* (2010) constructed a research framework on the impacts of different levels of logistics outsourcing decisions on logistics service performance. Taking 114 food processing enterprises in the Netherlands and Taiwan as samples, the study found that logistics outsourcing had no direct impact on logistics service performance (delivery reliability, flexibility and lead time) [16]. Solakivi *et al.* (2011) conducted a survey of 223 small and medium-sized enterprises in Finland's manufacturing and trading industries and found that outsourcing did not have a positive or negative impact on logistics performance [17]. They believe that the efficiency of enterprises in handling logistics business is quite high, regardless of whether logistics are kept in the enterprise or outsourced. This means that the environment and the adaptability of outsourcing decisions may be more important performance drivers than outsourcing itself. Other literatures state that outsourcing enterprises may lose the control and operational flexibility of some functions and face the potential risk of exposing the enterprise's proprietary knowledge to suppliers, and these suppliers may become competitors in the future.

In terms of the interaction between the logistics industry and manufacturing industry, Jiang (2018) used the gray DANP decision model to determine the key factors of the interaction between the logistics industry and the manufacturing industry. The results show that the total number of employees, the number of goods, the total length of routes in the logistics industry, and the GDP and added value of the manufacturing industry are the key factors of the interaction [18]. Xing (2014) believes that the development level and degree of the logistics industry are directly related to the efficiency of manufacturing enterprises. The author designs a gray relational model to analyze the relationship between the manufacturing industry and logistics industry. The research shows that the two industries have a certain correlation, but they have not yet formed a benign relationship [19]. He (2020) uses the network DEA method to measure the production efficiency and service efficiency of the logistics industry, then takes the ''made in China 2025'' strategy as a natural experiment, and uses the double difference method to study the impact of manufacturing policy on the high-quality development of the logistics industry. The results show that compared with the control group, the effect of the ''made in China 2025'' strategy can significantly improve the production efficiency and service efficiency of the experimental group. Independent innovation has a significant positive impact on the high-quality development of the logistics industry. It is helpful to further promote the integrated development of the manufacturing industry and logistics industry [20].

The above literature conducts exploratory studies on the interaction between the logistics industry and the manufacturing industry. However, the existing literature on the dynamic impact of the interaction between the two industries is insufficient, the discussion on the regional differences of the interaction between the two industries is not deep enough, and there is little discussion on the differences of the interaction between the two industries according to the differences in logistics organization modes. To compensate for these defects, this paper selects two representative regions with different logistics organization modes and constructs and estimates the panel vector autoregressive model (PVAR) to conduct a comparative study.

Due to the performance results of logistics outsourcing in different countries and regions, there are fuzzy and contradictory conclusions in different industries. With increasingly more enterprises adopting logistics outsourcing in China, it is necessary to study the interactive relationship between the logistics industry and manufacturing industry under different logistics organization modes in China to enhance enterprises' confidence in logistics outsourcing and further promote the linkage development between the logistics industry and other industries, especially the manufacturing industry.

III. RESEARCH HYPOTHESIS

A. INTERACTION MECHANISM OF THE EFFICIENCY BETWEEN THE LOGISTICS INDUSTRY AND MANUFACTURING INDUSTRY

1) IMPACT MECHANISM OF THE LOGISTICS INDUSTRY ON MANUFACTURING EFFICIENCY

The logistics industry is the link connecting the upstream and downstream industries in the operation of the national economy. The construction of an efficient logistics network system can drive the circulation of production factors and commodities, solve the contradiction of goods and materials in time and space, and promote the optimal allocation of production factors among different industries. Logistics will run through the whole manufacturing process. Therefore, the costs of the manufacturing industry are also affected by logistics costs [21]–[24]. In addition, the response speed of the manufacturing industry to the market is also affected by the timeliness of logistics, which affects production efficiency.

(a) The logistics industry reduces the production costs of the manufacturing industry. The costs and scale of logistics enterprises are closely related. Different from manufacturing enterprises in the internal construction of their own logistics system, when the scale of logistics enterprises continues to expand, the human costs, R&D costs and technical costs of enterprises will be correspondingly reduced, to provide lower cost logistics services for the manufacturing industry. That is, the logistics industry, as a productive service industry, has the advantages of economies of scale. In addition, with the rapid development of the logistics industry, practical experience constantly accumulates and improves the management level to highlight its own advantages in logistics services to provide customers with higher value-added logistics services. Relevant scholars have proposed that logistics enterprises can provide customers with relevant information services and inventory services, which are conducive to customers' great control of enterprise costs. For example, this kind of high-quality information service can allow customers to obtain all kinds of data and information they need while inventory service can allow customers to reasonably control enterprise orders, ensure the timely delivery of orders, and greatly reduce logistics costs [25]–[29].

(b) The logistics industry reduces the transaction costs between the manufacturing industry and logistics industry. When the economic subject is engaged in relevant economic exchange activities, all the related costs are transaction costs. The two sides of the transaction will sign a relevant contract, but the terms of the contract cannot cover all possible matters. In this case, the trust of both parties can play a role in reducing the negotiation costs. The emergence of modern logistics can make information more open and transparent so that both sides of the transaction have a reasonable expectation of the outcome of the transaction. With the deepening of the linkage between the two industries, the trust of the transaction subject in the other side is constantly improved, thus reducing the possible risks of the transaction and greatly controlling the transaction costs [30], [31].

(c) The logistics industry promotes the manufacturing industry to continuously improve its technical level. Increasingly more studies show that the logistics industry, as a producer service industry, needs high-tech support, has a strong innovation ability, and can guide and promote the innovation of manufacturing enterprises. The logistics industry can guide the manufacturing industry to continuously improve its level of enterprise innovation to promote the sharing of knowledge and technology among enterprises and ultimately enhance the innovation ability of the manufacturing industry. In addition, with the reduction of logistics service costs brought by high-tech developments, the costs of the manufacturing industry are also reduced, and the profit space of enterprises is further expanded to increase the investment in technological research and development. Moreover, the outsourcing of logistics services by manufacturing enterprises shortens the cycle of innovation and reduces the expenses caused by innovation activities. In addition, with the technological innovation of the industry and the rapid spread of knowledge and information, the relationship between the industries is becoming increasingly closer, and the strengthening of industrial cooperation also greatly promotes enterprises to implement independent innovation [32], [33]. The joint development of leading products and the joint development of the market by the two industries promotes the exchange of knowledge and information between industries and greatly improves the technological innovation ability of the two industries.

2) IMPACT MECHANISM OF THE MANUFACTURING INDUSTRY ON LOGISTICS INDUSTRY EFFICIENCY

(a) The scale of the manufacturing industry affects the development scale of the logistics industry

Logistics is a service-oriented support system for the overall industrial development of a region [34]. It has many characteristics of the service industry. Only when it is integrated into the whole industrial chain can its value be maximized. Only when it participates in the circulation of production, manufacturing and commercial trade can the linkage value of logistics be reflected. From a macro point of view, the more concentrated and developed the manufacturing industry in a region is, the greater the market space for development, and the higher the market share and overall profits of the logistics industry. Therefore, the development scale of the logistics industry in a region depends on the scale of the local manufacturing industry.

(b) The development level of the manufacturing industry determines the development level of the logistics industry The logistics industry develops with the development of the economy. Different classes of economic development and the definition and connotation of the logistics industry are also different [35]. The development level of the whole logistics industry in a region is mainly determined by the economic development level of the region. The level of economic development is mainly reflected in the development level of the local manufacturing industry and the size of the whole manufacturing industry agglomeration. If the whole manufacturing industry is very concentrated and all types of products are gathered together to form an industrial cluster, then a complete supply chain will be formed in the local area. At this time, the whole economic development level will be correspondingly improved due to the formation of the supply chain, and the logistics industry also needs higher-level logistics services to meet the needs of the developed economy.

(c) The economic structure of manufacturing determines the structure of logistics

From past experience, in different regions, the economic structure is also very different, the overall industrial structure is not the same, and the industrial structure has a great impact on the structure of the logistics industry in the region. Resource-based cities will form industrial clusters around the mining and processing of resources [36]. The logistics structure of these cities is mainly the rail and water transportation of bulk goods. In coastal and high-tech development zones, the transportation network is relatively developed. Such areas often have higher requirements for the timeliness of products, which also determines the development direction of the logistics structure in such areas in terms of intensification and scale. Therefore, the economic structure of manufacturing determines the structure of logistics.

(d) Manufacturing agglomeration promotes the development of the logistics industry

The manufacturing industry forms a good economic whole by deepening cooperation among related industries. Here, enterprises cooperate with each other and compete with each other and occupy certain market shares. Therefore, in this situation, logistics plays a great role in coordination and facilitation. If there is no perfect logistics service, it is very difficult to achieve an effective connection in each link of the economy as a whole. The circulation of goods and information is not smooth, and economic development is hindered. Therefore, the agglomeration of the manufacturing industry further promotes the development of the logistics industry and provides a larger market. Therefore, in this form, the logistics industry has gradually evolved into a modern industry matching the modern manufacturing industry and formed a certain scale [37].

Based on the above theoretical analysis, this paper proposes the following assumptions:

H1a: The development of the logistics industry has a direct impact on the development of the manufacturing industry and has a significant role in promoting it.

H1B: The development of the manufacturing industry has a direct impact on the development of the logistics industry and has a significant role in promoting it.

B. ADJUSTMENT MECHANISM OF THE LOGISTICS ORGANIZATION MODE ON THE MANUFACTURING INDUSTRY

1) SELF-OWNED LOGISTICS MODE

In general, self-owned logistics enterprises have higher and additional management costs. This is mainly reflected in the following aspects. The first is the coordination costs between the logistics department and the production department. Second, compared with managers in specialized logistics organizations, managers in manufacturing enterprises have a comparative disadvantage in management efficiency [38].

2) OUTSOURCING LOGISTICS MODE

The logistics outsourcing mode refers to the mode of joint governance of both sides of logistics transactions (manufacturing enterprises and logistics enterprises), which is used for repeated transactions supported by mixed and highly specific investment. The characteristics of this kind of logistics market are as follows: first, both the logistics industry and the manufacturing industry have the motivation to maintain the transaction relationship rather than let it terminate to avoid sacrificing the valuable transaction-specific economy. Second, both the logistics and manufacturing industries have gained profit streams and will not easily agree to any contract adjustment proposal [39]. Furthermore, the logistics industry and manufacturing industry, which form an intermediate organization, not only maintain their relative independence, but they also compete among the members of the organization to maintain higher market efficiency to avoid the organizational costs caused by rigid failure in the integrated organization.

Based on the above theoretical analysis, this paper proposes the following assumptions:

H2A: Self-owned logistics negatively regulate the efficiency of the linkage development of the logistics industry and manufacturing industry. The higher the proportion of self-owned logistics is, the stronger the impact of logistics development on the development of the manufacturing industry.

H2B: Logistics outsourcing positively regulates the efficiency of the development of the linkage of the logistics industry and manufacturing industry. The higher the proportion of outsourcing is, the stronger the impact of logistics development on the development of the manufacturing industry.

IV. AN EMPIRICAL ANALYSIS OF THE INTERACTION BETWEEN THE LOGISTICS INDUSTRY AND MANUFACTURING INDUSTRY UNDER DIFFERENT MODES

A. RELATIONSHIP MODEL CONSTRUCTION AND INDEX SELECTION OF THE LOGISTICS INDUSTRY AND MANUFACTURING INDUSTRY

1) MODELING THE EFFICIENCY MEASUREMENT

Before analyzing the interactive relationship between the efficiency of the logistics industry and manufacturing industry, the research needs to measure the efficiency of the logistics industry and manufacturing industry. In this chapter, the paper chooses the range adjusted measure model (RAM model) proposed by Aida to measure the efficiency [40].

The RAM model can not only eliminate the problems of "angle", "radial" and the traditional DEA model, but it also has an additive structure; therefore, it can measure the economic efficiency, environmental efficiency and joint efficiency of the economy and environment. Since the efficiency of the logistics industry and the efficiency of the manufacturing industry refer to the joint efficiency of the economy and environment of the logistics industry and manufacturing industry, the following calculation model of joint efficiency considering the economy and environment is built.

The RAM model of economic efficiency is as (1), shown at the bottom of the page.

where x_{nj} and y_{pj} denote the nth common input factor and the pth expected output factor of region J, respectively; λ_j denotes

$$max \left\{ (\sum_{n=1}^{N} R_n^x s_n^x + \sum_{p=1}^{p} R_p^y s_p^y) \left| \begin{array}{l} \sum_{j=1}^{J} x_{nj}\lambda_j + s_n^x = x_{nj}, \forall n; \sum_{j=1}^{J} y_{pj}\lambda_j - s_p^y = y_{pj}, \forall p; \\ \sum_{j=1}^{J} \lambda_j = 1, \lambda_j \geq 0, \forall j; s_n^x \geq 0, \forall n; s_p^y \geq 0, \forall p; \end{array} \right. \right\} \quad (1)$$

the weight of region J; and R_n^x and R_p^y refer to the adjustment interval of the relaxation variables s_n^x and s_p^y, respectively. The specific expression is as follows:

$$\left.\begin{aligned} R_n^x &= \frac{1}{(N+P)\left[Max\left(x_{nj}\right)-Min\left(x_{nj}\right)\right]} \\ R_p^y &= \frac{1}{(N+P)\left[Max\left(y_{pj}\right)-Min\left(y_j\right)\right]} \end{aligned}\right\} \quad (2)$$

Assume that λ^* represents the weight of the cross-sectional observation value that each region may use to reach the maximum relative efficiency in the process of economic production when model (1) obtains the optimal solution state. $s_n^{x^*}$ and $s_p^{y^*}$ represent the relaxation variables of the input and output in the optimal solution state, respectively. At this time, the RAM economic efficiency index of region J in year t can be transformed into: λ^*

$$0 \le \theta_p = 1 - \left(\sum_{n=1}^{N} R_n^x s_n^{x*} + \sum_{p=1}^{p} R_p^y s_p^{y*}\right) \le 1 \quad (3)$$

The RAM model of environmental efficiency is as (4), shown at the bottom of the page, where e_{mj} and b_{ij} denote the *Mth* energy input factor and the *Ith* unexpected output factor of region J, respectively; $s_m^{e^+}$ and $s_m^{e^-}$ represents two relaxation variables of the *Mth* energy input; and "+" and "−" represent two projection directions (expansion and reduction) of energy, respectively.

$$\left.\begin{aligned} R_m^e &= \frac{1}{(N+M+I)\left[Max\left(e_{mj}\right)-Min\left(e_{mj}\right)\right]} \\ R_i^b &= \frac{1}{(N+M+I)\left[Max\left(b_{ij}\right)-Min\left(b_{ij}\right)\right]} \end{aligned}\right\} \quad (5)$$

In this paper, only the carbon dioxide emissions of the logistics industry and industrial wastewater discharge from the manufacturing industry are regarded as undesirable outputs, and s_m^{e+*}, s_m^{e-*} and s_i^{b*} represent the relaxation variables of the input and output in the optimal solution state. According to the above model (4), the RAM environmental efficiency index in year t of region J can be transformed into:

$$\begin{aligned} 0 &\le \theta_E \\ &= 1 - \left(\sum_{n=1}^{N} R_n^x s_n^{x*} + \sum_{m=1}^{M} R_m^e\left(s_m^{e+*} + s_m^{e-*}\right) + \sum_{i=1}^{I} R_i^b s_i^{b*}\right) \\ &\le 1 \end{aligned} \quad (6)$$

According to the additive structure of the RAM model, economic efficiency and environmental efficiency are integrated into a unified framework as (7), shown at the bottom of the page.

When model (7) obtains the optimal solution, the joint efficiency index of the RAM in year t of region J can be transformed into the following:

$$\begin{aligned} 0 \le \theta_U = 1 - \Bigg(&\sum_{n=1}^{N} R_n^x s_n^{x*} + \sum_{m=1}^{M} R_m^e\left(s_m^{e+*} + s_m^{e-*}\right) \\ &+ \sum_{p=1}^{p} R_p^y s_p^{y*} + \sum_{i=1}^{I} R_i^b s_i^{b*}\Bigg) \le 1 \end{aligned} \quad (8)$$

2) INTERACTIVE RELATIONSHIP MODEL CONSTRUCTION

In 1980, Christopher Sims proposed the vector autoregressive (VAR) model, which is an innovation of the regression model. The VAR overcomes the limitations of economic theory and does not have any prior constraints. The VAR is usually used to study the prediction of time series systems and the impacts of random disturbances on variables. It has been widely used in the study of macro time series data. However, because there are many parameters to be estimated in the VAR model, if the sample size is too small, the estimation results of the model will be affected. In most research cases, time series data have difficulty meeting the requirements of the model. Furthermore, the VAR model cannot process panel data, which affects the application of the model in practice. To overcome these shortcomings, Holtz Eakin and other scholars proposed

$$max\left\{\begin{array}{l} \left(\sum\limits_{n=1}^{N} R_n^x s_n^x + \sum\limits_{m=1}^{M} R_m^e(s_m^{e^+} + s_m^{e^-}) + \sum\limits_{i=1}^{I} R_i^b s_i^b\right) \Bigg| \sum\limits_{j=1}^{J} x_{nj}\lambda_j + s_n^x = x_{nj}, \forall n; \\ \sum\limits_{j=1}^{J} e_{mj}\lambda_j - s_m^{e^+} + s_m^{e^-} = e_{mj}, \forall m; \sum\limits_{j=1}^{J} b_{ij}\lambda_j + s_i^b = b_{ij}, \forall i; \\ \sum\limits_{j=1}^{J} \lambda_j = 1, \lambda_j \ge 0, \forall j; s_n^x \ge 0, \forall n; s_m^{e^+} \ge 0, s_m^{e^-} \ge 0, \forall m; s_i^b \ge 0, \forall i \end{array}\right\} \quad (4)$$

$$max\left\{\begin{array}{l} \left(\sum\limits_{n=1}^{N} R_n^x s_n^x + \sum\limits_{m=1}^{M} R_m^e(s_m^{e^+} + s_m^{e^-}) + \sum\limits_{p=1}^{p} R_p^y s_p^y + \sum\limits_{i=1}^{I} R_i^b s_i^b\right) \Bigg| \sum\limits_{j=1}^{J} x_{nj}\lambda_j \\ + s_n^x = x_{nj}, \forall n; \sum\limits_{j=1}^{J} e_{mj}\lambda_j - s_m^{e^+} + s_m^{e^-} = e_{mj}, \forall m; \sum\limits_{j=1}^{J} y_{pj}\lambda_j - s_p^y = y_{pj}, \forall p; \\ \sum\limits_{j=1}^{J} b_{ij}\lambda_j + s_i^b = b_{ij}, \forall i; \sum\limits_{j=1}^{J} \lambda_j = 1, \lambda_j \ge 0, \forall j; s_n^x \ge 0, \forall n; s_m^{e^+} \ge 0, \\ \quad s_m^{e^-} \ge 0, \forall m; s_p^y \ge 0, \forall p; s_i^b \ge 0, \forall i \end{array}\right\} \quad (7)$$

the PVAR model in the 1980s. On this basis, relevant scholars have demonstrated and improved the PVAR model, and the model has gradually matured and quickly popularized.

The panel vector autoregressive model has the following characteristics: first, the variable of the model is panel data. When the length of the time series is fixed, the increase in the number of cross sections will enlarge the sample size, thus relaxing the requirement of the model for the time length of the data. In this model, when the length of the time series $t \geq m + 3$, the equation parameters can be estimated, where t is the time dimension and m representing the lag order of the model. When $t \geq 2m + 2$, the model can be estimated in the steady state. Second, the hypothesis of the model is more relaxed, which can solve the cross-sectional heterogeneity and individual effect problems in the model and can further expand to the spatial econometric model. Third, by expanding the sample size and reducing the multicollinearity among independent variables, the model can make the analysis results more robust.

From the above analysis, it can be seen that the logistics industry and manufacturing industry interact and influence each other. The panel vector autoregressive model takes the target variable as an endogenous vector system to study the interaction between variables, which is suitable for the analysis of the impact relationship of the logistics industry.

Therefore, the function form of the PVAR model set in the paper can be expressed as follows:

$$y_{it} = \alpha_0 + \sum_{j=1}^{k} \Gamma_j y_{i,t-j} + \eta_i + \mu_t + \varepsilon_{it} \tag{9}$$

In this equation, $y_{it} = (WL, ZZY)$ are two endogenous variables: WL is the logistics industry, and ZZY is the manufacturing industry. i is different cities; t is the year; α_0 is intercept term; γ_t is time effect of observation; Γ_j is the coefficient matrix; η_i is the heterogeneity of different cities; μ_t is the trend characteristic of the system variable, which is specific impact effect of each year; and ε_{it} is random disturbance term.

The steps of the panel vector autoregressive model are as follows: first, the panel unit root test and panel cointegration test are conducted for each variable sequence. After passing the unit root test, the lag order of the PVAR model is determined by the information criterion. After the variable passes the unit root test, the cointegration test can be conducted if it is a single integration of the same order. The cointegration test examines whether there is a long-term equilibrium relationship between variables by testing whether the nonstationary variable sequence presents stationarity after combination. Second, the PVAR model uses the Monte Carlo simulation method to estimate and then generate an impulse response function image. Impulse response function analysis assesses the influence of the variation of the endogenous variable error term on each variable. Third, variance decomposition is used to further measure the contributions of different factors to the impact of the endogenous variables. Variance decomposition analysis decomposes the changes in endogenous variables into component shocks to the panel vector autoregressive system to describe the contribution of each variable to the impact and further analyzes the interaction between variables. The empirical analysis in this chapter mainly uses the Stata 13 statistical software to conduct the quantitative analysis of all panel data.

3) INDEX SELECTION

Referring to the index selection of most scholars, this paper selects the freight volume and industrial added value to represent the logistics industry and manufacturing industry, respectively [41], [42]. The PVAR model data in this paper are based on the data of 34 prefecture-level cities in Northeast China from 2006 to 2018 (due to lack of data, Daxing'an Mountain Range and Yanbian Korean Autonomous Prefecture are not included) and 27 prefecture-level cities in the Yangtze River Delta region (outline of the regional integration development planning of Yangtze River Delta issued on December 1, 2019) from 2016. In addition, to eliminate the heteroscedasticity of time series, the data are processed logarithmically.

B. EMPIRICAL ANALYSIS OF THE RELATIONSHIP BETWEEN THE LOGISTICS INDUSTRY AND MANUFACTURING INDUSTRY UNDER DIFFERENT MODES

Before the establishment of the PVAR model, to ensure the effectiveness of the model estimation parameters, it is necessary to effectively select the optimal lag time of the model and to avoid the influence of lag orders that are too large or too small on the model parameter estimation. In practical applications, the order of the minimum values of the AIC, BIC and HQIC is generally selected as the optimal lag order. The values of the lag order under different criteria are shown in Table 1 below.

TABLE 1. Test results of lag order.

lag	AIC	BIC	HQIC
1	0.768362	1.64871	1.12052
2	1.41928	2.43488	1.82715
3	-0.246956*	0.930775*	0.227851*
4	-0.068322	1.31216	0.490282

Through the calculation of the AIC, BIC and HQIC, it is found that these values reach their minimum values after three lag periods. Therefore, the above table shows that 3 is the optimal lag order of the model constructed in this study.

1) JUDGMENT OF THE EQUILIBRIUM RELATIONSHIP BETWEEN THE LOGISTICS INDUSTRY AND MANUFACTURING INDUSTRY UNDER DIFFERENT MODES

The logarithm (lnZZY) sequence of industrial added value (lnZZY) representing the manufacturing industry is tested. The results show that the p value of lnZZY is less than.01

and the p value under the level is lower than .01. That is, lnZZY passes the unit root test, and the sequence is stable (see Table 2). Similarly, the number (lnWL) series representing the freight volume of the logistics industry is tested, and the results also pass the unit root test. In addition, the above-mentioned stationarity test shows that the variables lnZZY and lnWL analyzed in this paper have stable equilibrium relationships in both the short term and long term. This shows that there is a long-term equilibrium relationship between the logistics industry and manufacturing industry in the entire study area.

TABLE 2. Stability test results.

variable	IPS test		Fisher-ADF test		Fisher-PP test		stable
	statistic	p value	statistic	p value	statistic	p value	
lnZZY	-21.8908	0.0000	481.3361	0.0000	109.1757	0.0011	Yes
lnWL	-9.8641	0.0000	564.8564	0.0000	180.8324	0.0000	Yes
variable	IPS test		Fisher-ADF test		Fisher-PP test		stable
	statistic	Pvalue	statistic	Pvalue	statistic	Pvalue	
lnZZY	-21.8908	0.0000	481.3361	0.0000	109.1757	0.0011	Yes
lnWL	-9.8641	0.0000	564.8564	0.0000	180.8324	0.0000	Yes

2) JUDGMENT OF THE CAUSALITY BETWEEN THE LOGISTICS INDUSTRY AND MANUFACTURING INDUSTRY UNDER DIFFERENT MODES

The above table shows that the probability that lnZZY is not the Granger cause of lnWL is 0.007, which is less than the significance level of 0.05. Therefore, the original hypothesis is rejected, and lnZZY is the Granger cause of lnWL. Therefore, the above table shows that the Granger test results all reject the original hypothesis. There is two-way Granger causality between manufacturing and logistics. That is, the manufacturing industry and logistics industry Granger cause each other in a statistical sense.

3) JUDGMENT OF THE DYNAMIC RELATIONSHIP BETWEEN THE LOGISTICS INDUSTRY AND MANUFACTURING INDUSTRY UNDER DIFFERENT MODES

The impulse response function describes the dynamic impact of the disturbance of a variable on every variable in the system when the current and previous values of other variables remain unchanged. The impulse response function intuitively displays the dynamic interaction effect and time delay relationship between variables by analyzing the degree of influence and direction of each variable on the current and future impacts to show the dynamic relationship between variables in the model more vividly.

To further investigate the dynamic influence between the development of the logistics industry and manufacturing industry, an impulse response function is used. In this paper, the pulse response function is obtained by 200 Monte Carlo simulations.

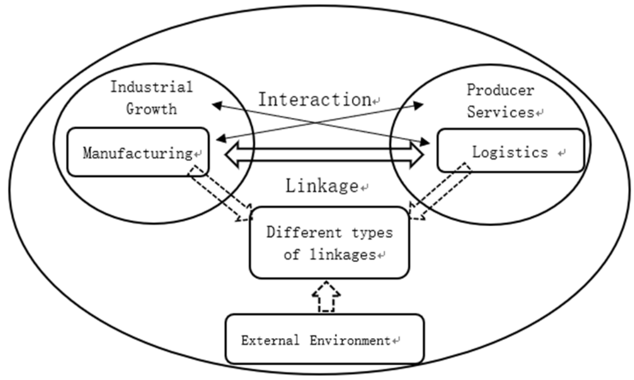

FIGURE 1. The relationship between logistics and manufacturing.

The upper left corner of Figure 1 shows the manufacturing industry's response to its own shocks. It has a strong positive response in stage 0 and then decreases rapidly. This positive response weakens to a negative impact at approximately stage 5, then continues to decline, reaches the lowest value around phase 6, and then rises slowly and approaches 0 stably in the long run. The impact of the whole process shows that the manufacturing industry will have a positive impact on itself in the early stage. In the long run, the positive impact will gradually weaken or even exhibit a negative impact, and the impact trend tends to zero.

The upper right corner shows the response of the manufacturing industry to the impact of the logistics industry. The overall trend is an ''inverted U-shaped''. The impact is zero at the initial stage, then rises rapidly, reaches the peak around the fifth period, then decreases rapidly, and then tends to be a stable positive value after the tenth period. This shows that the development of the manufacturing industry can promote the development of the logistics industry, and this kind of influence is more lasting; however, the effect has a time lag.

The lower left corner is the response of logistics development to the impact of manufacturing development. The overall trend is ''U-shaped''. The impact is positive in period 0, then negative impact and rapidly decreasing in the second phase, then decreases to the lowest value around the fifth period, then slowly rises, and finally tends to a stable positive number, tending to 0. This shows that the development of the logistics industry has a positive impact on the development of the manufacturing industry in the short term, but the effect is small and the time is short. In the long run, the development of the logistics industry always has a negative impact on the manufacturing industry, but the impact is on the rise. In other words, in the long run, the contribution of the development of the logistics industry to the manufacturing industry has been rising, and the effect time is long.

The lower right corner is the response of the logistics industry development to its own impact. Overall, the graph has a straight-line downward trend. The graph shows that the logistics industry has a positive impact on its own development, and the impact is more lasting; however, the effect is time-delayed.

TABLE 3. Granger test results.

Equation	Excluded	chi2	df	Prob > chi2
h_lnZZY	h_lnWL	12.255	3	0.007
h_lnZZY	ALL	12.255	3	0.007
h_lnWL	h_lnZZY	10.687	3	0.014
h_lnWL	ALL	10.687	3	0.014

Through the above analysis, it is not difficult to find that the northeastern manufacturing industry has a greater role in promoting the development of the logistics industry, and it has timeliness. From the response of the development of the logistics industry to the impact of the manufacturing industry, the logistics industry has hindered the development of the manufacturing industry to a certain extent. The results also show that the logistics industry in the region has insufficient power to promote the development of the manufacturing industry under the self-owned logistics mode.

The impulse response function preliminarily analyzes the interaction between the logistics industry and manufacturing industry. To measure the size and degree of the impact, variance decomposition is needed for the analysis.

Table 4 shows the variance decomposition results of the endogenous variables in Northeast China. The table shows that the results of the variance decomposition of each variable after the tenth period are basically the same, indicating that the degree of explanation of the relationship between the logistics industry and manufacturing industry is relatively stable in the long term.

The variance of the manufacturing industry is stable from the tenth period at 78.9%. The ability of the manufacturing industry to explain the development and change of the logistics industry increased gradually, reaching 21.1% in the tenth period, and then remained unchanged.

Regarding the variance decomposition of DIS, the ability of the logistics industry to explain its variance changes gradually decreased, reaching 86% in the 12th period, and then remained stable. The ability of the logistics industry to explain the development and changes of the manufacturing industry increased gradually, reaching 14% in the twelfth period, and then remained stable.

The upper left corner of Figure 2 shows the manufacturing industry's response to its own shocks with a strong positive response in period 0 and then a rapid decline. The positive reaction was stable and close to 0 in the ninth cycle. The impact of the whole process shows that the early manufacturing industry will have a positive impact on itself. In the long run, the positive impact gradually weakened, and the impact trend tended to zero.

The upper right corner shows the manufacturing industry's response to the impact of the logistics industry. The overall trend is a stable "U-shaped". The initial impact is zero, then decreases rapidly, reaches the lowest point before and after the third cycle, then increases slowly, and tends to the initial value after the ninth cycle. This shows that the development

TABLE 4. Variance decomposition of the logistics industry and manufacturing industry in Northeast China.

	s	lnZZY	lnWL
lnZZY	1	1.000	0.000
lnWL	1	0.017	0.983
lnZZY	2	0.970	0.030
lnWL	2	0.025	0.975
lnZZY	3	0.943	0.057
lnWL	3	0.032	0.968
lnZZY	4	0.898	0.102
lnWL	4	0.057	0.943
lnZZY	5	0.857	0.143
lnWL	5	0.082	0.918
lnZZY	6	0.825	0.175
lnWL	6	0.104	0.896
lnZZY	7	0.806	0.194
lnWL	7	0.119	0.881
lnZZY	8	0.796	0.204
lnWL	8	0.129	0.871
lnZZY	9	0.791	0.209
lnWL	9	0.135	0.865
lnZZY	10	0.789	0.211
lnWL	10	0.138	0.862
lnZZY	11	0.789	0.211
lnWL	11	0.139	0.861
lnZZY	12	0.789	0.211
lnWL	12	0.140	0.860
lnZZY	13	0.789	0.211
lnWL	13	0.140	0.860
lnZZY	14	0.789	0.211
lnWL	14	0.140	0.860
lnZZY	15	0.789	0.211
lnWL	15	0.140	0.860

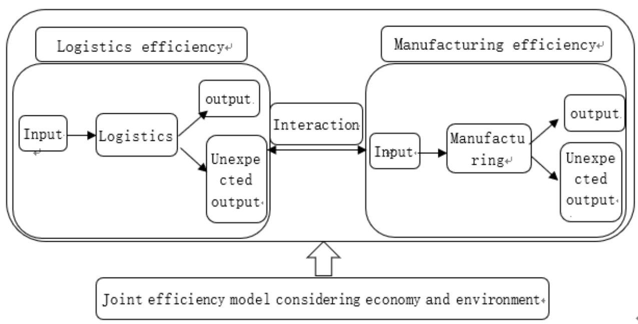

FIGURE 2. The joint efficiency structure of the logistics industry and manufacturing industry.

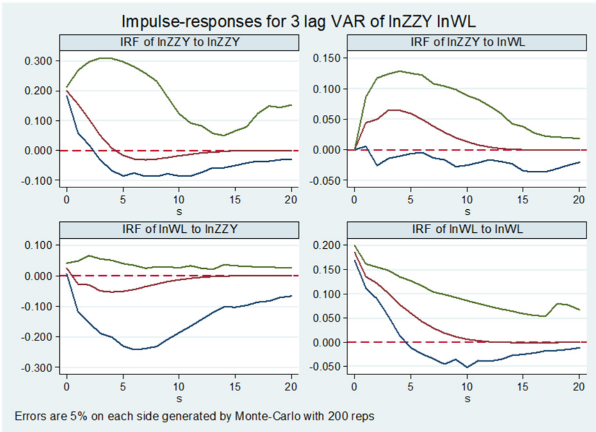

FIGURE 3. The impulse response function of the logistics industry and manufacturing industry in Northeast China under the self-owned logistics mode.

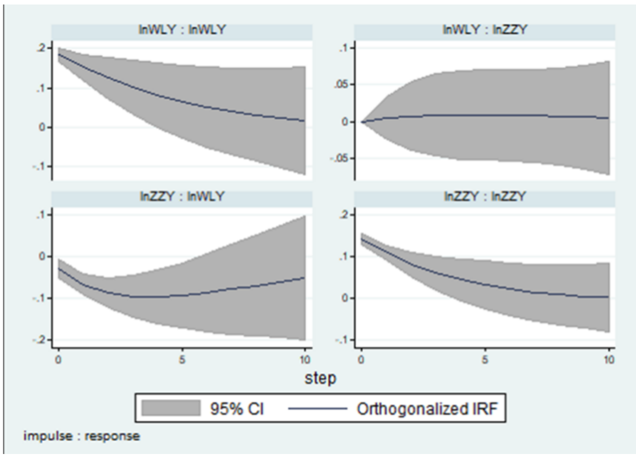

FIGURE 4. The impulse response functions of the logistics industry and manufacturing industry in the Yangtze River Delta under the logistics outsourcing mode.

of the manufacturing industry does not significantly promote the development of the logistics industry, and the impact is more lasting.

The lower left corner is the response of logistics development to the impact of manufacturing development. The development of the logistics industry has a long-term positive impact on the development of the manufacturing industry, but the impact is small, and a positive impact is maintained.

In the lower right corner is the response of the development of the logistics industry to its own influence. After the tenth period, the logistics industry tends to decline in a straight-line trend. Therefore, the logistics industry has a positive impact on its own development, and the impact is more lasting; however, the impact has a time lag.

Through the above analysis, it is found that the logistics industry plays an important role in promoting the development of the manufacturing industry under the logistics outsourcing mode in the Yangtze River Delta region. However, regarding the response of the manufacturing industry to the impact of the logistics industry, the manufacturing industry has not significantly promoted the development of the logistics industry.

TABLE 5. Variance decomposition of the logistics industry and manufacturing industry in the Yangtze River Delta region.

	s	lnZZY	lnWL
lnZZY	1	1.000	0.000
lnWL	1	0.017	0.998
lnZZY	2	0.985	0.015
lnWL	2	0.008	0.992
lnZZY	3	0.983	0.017
lnWL	3	0.017	0.983
lnZZY	4	0.968	0.032
lnWL	4	0.029	0.971
lnZZY	5	0.957	0.043
lnWL	5	0.034	0.966
lnZZY	6	0.925	0.075
lnWL	6	0.045	0.955
lnZZY	7	0.906	0.094
lnWL	7	0.067	0.933
lnZZY	8	0.896	0.104
lnWL	8	0.099	0.910
lnZZY	9	0.871	0.129
lnWL	9	0.105	0.895
lnZZY	10	0.870	0.130
lnWL	10	0.105	0.895
lnZZY	11	0.871	0.129
lnWL	11	0.105	0.895
lnZZY	12	0.870	0.130
lnWL	12	0.105	0.895
lnZZY	13	0.871	0.129
lnWL	13	0.105	0.895
lnZZY	14	0.870	0.130
lnWL	14	0.105	0.895
lnZZY	15	0.871	0.129
lnWL	15	0.105	0.895

We continue to analyze the Yangtze River Delta region via variance decomposition. Table 5 shows the variance decomposition results of the endogenous variables in the scope of the study. The table shows that the results of the variance decomposition of each variable after the ninth period are basically consistent, indicating that the degree of explanation of the relationship between the two industries is relatively stable in the long run.

According to the variance decomposition of the manufacturing DIS, the explanatory power of the manufacturing industry to its variance changes decreased gradually, reaching 87.1% in the ninth period, and then remained stable. The explanatory power of the manufacturing industry for the development and change of the logistics industry increased gradually, reaching 12.9% in the ninth period, and then remained unchanged.

Regarding the variance decomposition of DIS, the ability of the logistics industry to explain its variance changes gradually decreased, reaching 89.5% in the ninth period, and then remained stable. The explanatory ability of the logistics industry for the development and change of the manufacturing industry increased gradually, reached 10.5% in the ninth period, and then remained unchanged.

In conclusion, by comparing the pulse response results of the logistics industry and manufacturing industry in three provinces of Northeast China and the Yangtze River Delta, it is found that the impulse response results of the logistics industry and manufacturing industry in different regions are completely different, and the direction and intensity of the impact are also completely different. The northeast manufacturing industry has a greater role in promoting the development of the logistics industry, and it has a real-time effect. The response of logistics industry development to the impact of the manufacturing industry is negative, and the logistics industry has hindered the development of the manufacturing industry to a certain extent. In the Yangtze River Delta region, the logistics industry plays a more important role in promoting the development of the manufacturing industry, which is stable and lasting. The impact of the manufacturing industry on the development of the logistics industry is negative, which hinders the development of the logistics industry to a certain extent.

V. CONCLUSION

The linkage between the logistics industry and manufacturing industry is a continuous and interactive dynamic process. It is a type of activity that combines the logistics operations of the manufacturing industry and logistics industry based on their industrial association to promote the common development of both sides. In different stages of development, the interaction relationship between the logistics industry and manufacturing industry is not equal, and the mode and degree of the interaction between them are quite different.

There are a large number of state-owned enterprises in the old industrial base of Northeast China. The logistics services of these enterprises are generally provided by state-owned enterprises themselves. In contrast, the logistics services of the manufacturing industry in the Yangtze River Delta are provided by third-party logistics companies. To conduct a comparative study, this paper divides the linkage between the logistics industry and manufacturing industry into the self-owned logistics mode and the logistics outsourcing mode. This paper compares and analyzes the northeast region with the state-owned logistics mode as the main mode and the Yangtze River Delta region with logistics outsourcing service as the main mode.

The impulse response results of the logistics industry and manufacturing industry under different logistics organization modes are completely different, and the direction and intensity of the impact also completely vary. The northeast manufacturing industry has a greater role in promoting the development of the logistics industry, and it has a real-time effect. The response of logistics industry development to the impact of the manufacturing industry is negative, and the logistics industry has hindered the development of the manufacturing industry to a certain extent. In the Yangtze River Delta region, the logistics industry plays a more important role in promoting the development of the manufacturing industry, which is stable and lasting. The impact of the manufacturing industry on the development of the logistics industry is negative, which hinders the development of the logistics industry to a certain extent. The results show that there is great discrepancy in the development directions of the logistics industry and manufacturing industry under different logistics organization modes.

According to the above research results, this paper provides some management suggestions for the interaction and integration of the logistics and manufacturing industries in Northeast China and Yangtze River Delta: First, we should continue to vigorously develop third party logistics; improve the service level, professional level and economies of scale advantages of third party logistics enterprises; and help the manufacturing industry to reduce costs, increase efficiency, and transform and upgrade. Second, according to the differences of local manufacturing logistics demand and logistics organization mode, each region should formulate corresponding logistics development policies in line with local development. Finally, with the continuous attention of society to the environment, the development policies of the logistics industry and manufacturing industry formulated by relevant managers should not only consider the economic benefits but also consider the environmental impacts.

Indicators and the limitations of this article: In the research's data acquisition because the logistics industry is a network industry involved in many industries, in the present stage, a systematic evaluation index of the efficiency of the logistics industry is still lacking; there is currently no authoritative logistics statistical indicators in China; and compared to urban logistics and manufacturing data, the availability of expected output data is poorer. Further research: With the development of informatization, big data and the Internet of Things, more extensive research can be conducted on index selection and data acquisition in the future.

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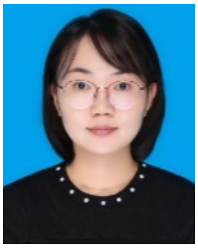

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