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The Relationship between Transportation Industry Efficiency, Transportation Structure, and Regional Sustainability Development in China: Based on DEA and PVAR Models

Zhuyuan Li [1], Tianxu Hao [1] and Run Zheng [2,*]

[1] College of Business Administration, Wonkwang University, No. 460, Iksandae-ro, Iksan 54538, Korea
[2] Business School, Jiangsu Open University, Nanjing 210036, China
* Correspondence: zhengrun100@163.com; Tel.: +86-152-9577-0401

Abstract: The sustainable development of the transportation industry has always been a major concern after China's reform and opening up. Existing studies only examine the transportation efficiency of a single mode of transportation or a certain region without considering the overall efficiency of the national transportation industry. Furthermore, most studies do not consider the impact of transportation structure on transportation efficiency and economic development. Moreover, the correlations and interactions between transportation efficiency, transportation structure, and regional economic development have not been considered. Based on the research status, this study uses a panel vector autoregressive model to analyze the relationship between the three. The results show that the transportation efficiency value is the highest in the eastern region, followed by the central region, and it is the lowest in the western region. The equilibrium degree of transportation structure has a slight difference in the national transportation structure from 2011 to 2020, and the proportion of major transportation modes in each province is unchanged. The correlation of the three variables is as follows: (1) transportation efficiency and transportation structure have a mutually reinforcing effect in the short term; (2) regional economic development has a long-term contribution to transportation efficiency and structure improvement; and (3) the level of transportation efficiency plays a leading role in regional economic development. According to the empirical analysis results, this study puts forward relevant feasible suggestions for the decision makers who formulate the development policies of the transportation industry in order to optimize the structure, reduce resource waste, improve the service quality of various transportation modes, and promote the high-quality, sustainable development of the transportation industry and economy.

Keywords: transportation efficiency (TE); transportation structure (TS); regional economic development (GDP)

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1. Introduction

The transportation industry is the basic industry of the national economy. Sound construction and development of the transportation industry will help realize economic connectivity and sustainable economic growth [1,2]. After China's reform and opening up, the transportation industry has been developing rapidly with the support of policies and funds, and a well-developed transportation system can help improve regional economic development [3]. In recent years, road transportation and railway transportation have occupied an increasingly important position in the current transportation system of their own advantages. In terms of infrastructure, by the end of 2021, the total operating mileage of the National Railways exceeded 150,000 km, including 40,000 km of high-speed railways. The rate of railroad duplication was 59.5%, and the electrification rate was 73.3%. The density of the national railroad road network was 156.7 kilometers per 10,000 square kilometers. The total mileage of highways reached 5,280,700 kilometers, an increase of 82,600 kilometers over the end of the previous year. The road density was 55.01 km/100 km^2, an increase of 0.86 km/100 km^2. The road maintenance mileage was 5.2516 million kilometers, accounting for 99.4% of the total road mileage. In terms of passenger and cargo volume, railway transportation completed 2.612 billion passengers throughout the year, an increase of 18.5% over the previous year, and completed 956.781 billion passenger kilometers, an increase of 15.7%. The annual total cargo delivery volume was 4.774 billion tons, an increase of 4.9% over the previous year, and the total cargo turnover was 3323.8 million ton-kilometers, an increase of 8.9%. Road transportation completed 5.087 billion business passenger transportation in the whole year, a decrease of 26.2% over the previous year, and completed 362.754 billion person-kilometers, a decrease of 21.8%. The annual business freight was 39.139 billion tons, an increase of 14.2% over the previous year, to complete the cargo turnover of 690,865 million ton-kilometers, an increase of 14.8%. The annual average transportation volume of motor vehicles for the year was 14,993 vehicles per day, an increase of 4.9% over the previous year, and the annual average travel volume was 348,692,000 vehicle kilometers per day, an increase of 3.6% [4].

According to the above data, inter-regional passenger transportation has increased, and the transportation demand has been growing [5]. The demand for transportation promotes economic development, but the rapid expansion of market capacity also intensifies market competition. This has led to excessive differences in transport volumes undertaken by various modes of transportation, resulting in an imbalanced transportation structure. The unreasonable transportation structure indirectly increases additional economic expenditure. Some urban transportation is not combined with local resources, and the output value contribution is not high, which may be the reason for the wide gap in economic development between regions. China's Fifth Plenary Session of the 19th Central Committee proposed accelerating the construction of a strong transportation country to promote the optimization and upgrading of the economic system. At the same time, it is also proposed to accelerate coordinated regional development, encourage the eastern region to speed up modernization, promote the rise of the central region and accelerate the development of the western region. Therefore, under the background of the rapid development of the national economy and transportation industry, how to effectively measure the transportation efficiency of the eastern, central and western regions and analyze the impact of transportation-related factors on regional economic development and economy has become an urgent problem to be discussed at this stage [6].

The issue of transportation efficiency has attracted the attention of researchers with the rapid development of the transportation industry [7,8]. The efficiency of transportation is one of the important symbols to measure the regional transportation structure and the level of regional economic development [9]. Through the study of transportation efficiency, we can analyze the investment and development direction of the transportation industry, which is of high guiding significance to improving the efficiency of transportation resource utilization [9,10]. The traditional data envelopment analysis (DEA) is widely used by scholars at home and abroad as a tool to evaluate the efficiency of transportation, which is essentially an evaluation of the relative effectiveness among decision-making units (DMUs) with multiple inputs and outputs. The main feature is that there is no need to assign relative weights to input and output indicators, which is free from the constraints of subjectivity in evaluation, so the DEA method can reflect the actual objective state in which the decision units are located. Due to the statistical errors and environmental factors in the traditional DEA method, Fried et al. [11] developed a three-stage data envelopment analysis method. The three-stage data envelopment analysis (DEA) method can effectively remove environmental effects and statistical noise and has been widely used for efficiency analysis in various industries, such as hotel management [12], the banking industry [13], manufacturing industry [14], education industry [15], sports industry [16], urban construction industry [17] and transportation industry [18,19].

The transportation industry has experienced a variety of development modes in different stages of economic development, and the comprehensive transportation system structure also presents different characteristics. There are also differences in the allocation efficiency of transportation resources and the comprehensive transportation service level in each stage [20]. The development of the comprehensive transportation system in developed countries has a distinct trend of gradual increment, and the main problem to be solved is how to allocate it. In contrast, China's transportation industry is in a stage of rapid development, and all modes of transportation have greater room for development, so how to reasonably allocate the existing resources and how to coordinate the development of each mode of transportation is the most important problem to be solved in the development of China's transportation industry at present. Promoting the reasonable division of labor and collaboration of various modes of transportation and improving the efficiency of the comprehensive transportation system are urgently needed to realize the optimal allocation of transportation resources, improve the structural system of the transportation industry and enhance the level of comprehensive transportation services. This requires us to conduct a comprehensive and systematic analysis of the evolution characteristics of the structure of China's comprehensive transportation system and make an accurate assessment of the current stage of China's comprehensive transportation structure. The result of transportation activities is the spatial displacement of people or goods, while the transportation volume is the measurement of the final product and the final embodiment of the interaction results of transportation resources. Due to the different industrial characteristics of passenger and freight transportation, the combined volume of passenger and freight transportation is chosen to measure the structure of the comprehensive transportation system in this paper.

The regional economy refers to the total value of the national economy distributed in each administrative region and is the general term for the interconnectedness of social production sectors, distribution sectors and other economic sectors constituted in the administrative region [21,22]. The development of the regional economy is inseparable from the support of the transportation industry, and the development of the regional economy will also promote the development of the transportation industry. As China's economy shifts from high growth to high-quality development, the objective requirement is for each industry's development direction and industrial structure to be more reasonable and balanced. The panel vector autoregressive model is widely used to study the correlation and influence degree between multiple variables. Based on the random coefficients panel vector autoregressive model, Mou and Wang [23] conducted an empirical study on the impact of fiscal and monetary policies on employment and economic growth in 24 developed countries. Chen et al. [24] conducted an empirical study on the relationship between technology selection, industrial structure upgrading, and economic growth based on the semi-parametric spatial panel vector autoregressive model. At present, there are many types of research on the relationship between multiple variables by using the panel vector autoregressive model, but there is little research on the relationship between the regional economy and other variables, especially the relationship between the transportation industry and regional economic development.

In summary, this paper uses the three-stage data envelopment analysis method to assess the efficiency of the transportation industry [25–27]. With the help of information entropy theory, the equilibrium degree of the existing transportation structure is analyzed. Finally, from the point of view of coordinated development, the PVAR model is used to comprehensively analyze the relationship and influence of the degree of transportation efficiency, transportation structure, and regional economic development to promote the realization of high-quality, sustainable development of the transportation system and economy.

The contents of this study are as follows: firstly, we briefly introduce the advanced research and theoretical knowledge related to transportation efficiency, transportation structure, and regional economic development. Then, we introduce the corresponding measurement and evaluation methods and indicators for each variable in this paper, as well as present the data sources and data descriptions after analyzing the corresponding data and empirical studies. Finally, we put forward the conclusion, including research contributions, policy recommendations, research limitations, and future research directions.

The research objectives of this paper are as follows: (1) to analyze the current situation and trends of the development of the transportation industry in 28 provinces and cities in China, as well as the reasons for this current situation, using a combination of qualitative and quantitative analysis methods; (2) to introduce the concepts of structure information entropy and structural equilibrium of a comprehensive transportation system with the help of information entropy theory and to realize the most reasonable development direction of the transportation industry by studying the evolution characteristics and trends of structural equilibrium of comprehensive transportation; (3) to analyze the relationship between transportation efficiency, transportation structure and regional economic development through the panel vector autoregressive model, analyze the interrelationship and degree of influence and propose suggestions and directions for improvement.

The innovation of this paper is mainly reflected in the following aspects.

(1) There are few studies on the transportation industry, especially on transportation efficiency and transportation structure in China. Based on previous studies in the transportation industry, this study selects more appropriate input, output, and environmental variables from the real environment. Since the DEA model cannot directly eliminate random errors and external factors, an SFA regression analysis is needed to strip the external factors and noise from the solution results. The improved three-stage DEA model is used to better remove the external environmental factors and make the analysis results more accurate.
(2) The existing studies on the comprehensive transportation system are only qualitative studies on the scale quantity and proportional relationship. This paper introduces the concepts of information entropy and the equilibrium degree of the structure of a comprehensive transportation system with the help of information entropy theory. By studying the randomness and disorder degree of the comprehensive transportation system structure and the conversion efficiency between various transportation modes, we analyze the evolution characteristics and trends of the structure of China's comprehensive transportation system and evaluate and analyze the structure of the comprehensive transportation system from both qualitative and quantitative aspects.
(3) The existing domestic and foreign scholars' studies on the relationship between the transportation industry and economic development have only focused on the exploration of the relationship between infrastructure or a single mode of transportation and economic development and have not considered the internal factors of the transportation system. Therefore, this paper is an innovative approach to analyzing the interrelationship between transportation efficiency, transportation structural equilibrium, and regional economic development from the perspective of coordination by using a panel vector autoregressive model (PVAR).

2. Literature Review

2.1. Transportation Efficiency

Traditionally, efficiency has two main definitional directions. One is defined from the input perspective, which asserts that technical efficiency is the value of the minimum cost obtained when inputting a resource factor relative to the actual cost. Another direction is to consider technical efficiency from the point of view of yield [28]. Transportation efficiency is the ratio of the output of a transportation system to the input resources and is an important measure to assess and monitor for governance and policymaking purposes [5,29]. The sustainable transportation industry is characterized by efficient transportation, the most rational transportation structure and a continuous contribution to the economy [30]. Data envelopment analysis (DEA), as a relative efficiency evaluation method, has also been proposed to evaluate the sustainability of transportation. In recent years, more and more scholars have used DEA to analyze China's transportation efficiency. Gu et al. [31] analyzed the road transportation efficiency of Jiangsu Province by using the DEA-CCR model. The results show that road transportation efficiency is closely related to regional economic development. Chang YoungTae et al. [32] used the non-radial DEA method to analyze the environmental efficiency of China's transportation system. Wu [33] used DEA-BCC and DEA-CCR models to evaluate the effectiveness of national waterway transportation from 2006 to 2015. Tian, Tang, Che and Wu [3] used the super efficiency SBM model to evaluate and analyze the sustainability of regional transportation efficiency Table 1.

Table 1. Summary of transportation efficiency in the literature.

Ref.	Research Subjects	Mode	Method
Tian, et al. (2019) [3]	Sustainable efficiency	Regional transportation	DEA-CCR model
Wei, W (2019) [25]	Transportation efficiency	Road transportation	SUP-SBM model
Shiau, et al. (2010) [30]	Sustainable efficiency	Transportation sector	DEA-CCR model, RST
Gu, et al. (2008) [31]	Transportation efficiency	Road transportation	DEA-CCR model
Chang YoungTae, et al. (2013) [32]	Transportation efficiency	Transportation sector	DEA-SBM model
Wu Xiaofen (2022) [33]	Transportation efficiency	Waterway transportation	DEA(BCC,CCR) model

From previous studies, it is known that the DEA method is widely used for the measurement of efficiency problems. In summary, this paper selects the three-stage DEA-CCR model to evaluate the transportation efficiency of 28 Chinese provinces from 2011 to 2020.

2.2. Transportation Structure

Transportation structure refers to the proportion and composition of various transportation modes that make up the transportation system [20,34]. Specifically, it refers to the proportional relationship between the technical nature, layout, development resources, and input-output of various transportation modes in the transportation system. The equilibrium degree of a transportation system structure directly affects the allocation of limited transportation resources and determines the efficiency of an urban transportation system. With urbanization and motorization, transportation supply and demand become unbalanced. Transportation efficiency has become increasingly inefficient, and the energy crisis, transportation congestion, and environmental pollution have become increasingly serious, which has seriously hindered the sustainable development of cities [35]. For the study of industrial structure equilibrium degree, the most commonly used is information entropy theory. Dong, Wu and Peng [20] analyzed the evolution characteristics and trends of China's comprehensive transportation system structure from 1949 to 2014 based on the information entropy theory and the diffusion effect theory of leading industries. Yu et al. [36] revealed the evolution trend of the status and role of air transport in China's passenger transport system structure based on the information entropy theory. Zhu [37] used the theory and method of information entropy and equilibrium degree to evaluate gray correlation analysis of industrial structure and transportation structure in Guizhou Province Table 2.

Table 2. Summary of transportation structure in the literature.

Ref.	Research Subjects	Level	Method
Xu, et al. (2021) [6]	Transportation Structure	Country	Information Entropy Theory
Dong, et al. (2017) [20]	Transportation Structure	Country	Information Entropy Theory
Yu, et al. (2020) [36]	Air transport Structure	City	Information Entropy Theory
Zhu (2021) [37]	Transportation Structure	Region	Information Entropy Theory

Through the summary of domestic and foreign scholars' previous research on various industrial structures and with the help of information entropy theory, this paper introduces the concept of equilibrium degree of comprehensive transportation system structure. Through the randomness and disorder of the comprehensive transportation system and the efficiency of conversion between various modes of transportation, the current situation and trends of the structure of the comprehensive transportation system in China are analyzed.

2.3. Regional Economic Development

A regional economy refers to the gross national economic value distributed in each administrative region [21]. Regional economic development is the epitome of the national economy, with comprehensive and regional characteristics [22]. The measurement index of regional economic development is the total regional GDP within the administrative region [38]. In recent years, there have been many studies on the correlation between regional economic development and other economic variables using the panel vector autoregressive model. Based on the panel data of 31 provinces in China, Yan and Xu [39] used the PVAR model to analyze the dynamic relationship between financial industry agglomeration, technological innovation, and regional economic growth. Sun and Chen [40] evaluated and analyzed the correlation and impact of green finance development on technological progress and economic growth in 31 provinces of China based on the PVAR model. Feng [41], based on the PVAR model and China's provincial panel data from 2008 to 2019, studied the relationship between industrial structure change, green production efficiency, and regional economic growth. Cheng and Da [42] conducted an empirical study on the relationship between China's income balance, carbon emissions, and economic growth using the PVAR model based on China's provincial panel data Table 3.

Table 3. Summary of regional economic development in the literature.

Ref.	Research Subjects	Method
Yan, et al. (2019) [39]	Financial industry agglomeration, technological innovation, regional economic growth	PVAR
Sun, et al. (2019) [40]	Green finance development, technological progress, regional economic growth	PVAR
Feng (2021) [41]	Industrial structure change, green production efficiency, regional economic growth	PVAR
Cheng (2022) [42]	Income balance, carbon emissions, regional economic growth	PVAR

Through the summary of domestic and foreign scholars' previous research on regional economic development-related issues by using the PVAR model, in this paper, the panel vector autoregressive model is used to evaluate and analyze the relationship and the degree of influence between transportation efficiency, transportation structure, and regional economic development.

3. Research Methods

3.1. Data Collection

The data source used in this study is the National Bureau of Statistics of China and the *National Statistical Yearbook* [43], as well as the *Provincial and Municipal Statistical Yearbook* revised by the provincial statistical bureaus. The timespan of sample selection is 2011–2020. Due to the lack of original data in some provinces, only 11 provinces and cities in eastern China (Beijing, Tianjin, Hebei, Shandong, Liaoning, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan), 8 provinces in Central China (Shanxi, Jilin, Henan, Anhui, Heilongjiang, Hubei, Hunan, and Jiangxi), and 9 provinces and regions in Western China (Neimenggu, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, and Qinghai) are selected. The data from the National Bureau of Statistics and the *National Statistical Yearbook* are more complete, and the official statistics are highly accurate and authoritative, which can guarantee the accuracy of the analysis results. The specific analysis process is as follows in Figure 1.

3.2. Evaluation of Transportation Efficiency

In the empirical analysis, a modified three-stage DEA-CCR model was used. The DEA-CCR model was proposed by Charnes and Cooper in 1978 [44]. The model method projects the decision-making unit (DMU) onto the frontier through linear programming and judges its relative effectiveness according to the distance between the DMU and the frontier [24,37]. Compared with the traditional DEA model, the three-stage DEA model considers the influence of external environmental factors and random errors and can evaluate transportation efficiency more accurately [45]. The specific process is as follows:

In the first stage, the DEA-CCR model is used to evaluate the initial efficiency. Let $x = (x_1, x_2, \ldots, x_m)^T$ be the input vector of a DMU, $y = (y_1, y_2, \ldots, y_s)^T$ be the multiple output vectors corresponding to that DMU, and use (x, y) to represent the whole economic activity of all DMUs.

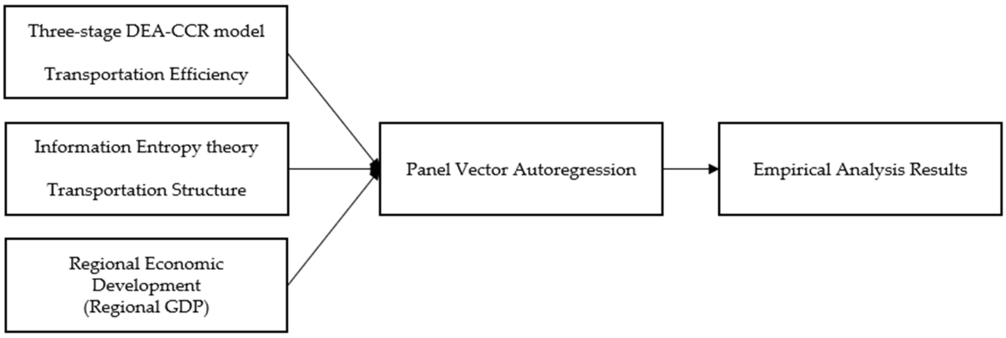

Figure 1. Analysis process flow chart.

Assuming that there are n DMUs and m input indicators, the model can be built as follows:

$$\begin{cases} min\theta \\ s.t \cdot \sum_{j=1}^{n} \lambda_j x_j + s^+ = \theta \cdot x_0 \\ \sum_{j=1}^{n} \lambda_j y_j - s^- = y_0 \\ \lambda_j \geq 0, j = 1, 2, \cdots, n \\ \theta \text{ unconstrained}, s^+ \geq 0 s^- \geq 0 \end{cases} \tag{1}$$

$$x_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T > 0\ , j = 1, 2, \cdots\cdots n;$$
$$y_j = (y_1 j, y_2 j, \cdots, y_s j)^T > 0,\ j = 1, 2, \ldots\ldots n;$$
$$x_{ij} > 0, y_{ij} > 0, i = 1, 2, \cdots, m; r = 1, 2, \cdots, s$$

x_{ij} and y_{ij} are the actual observations of input and output indicators, either cross-sectional, time-series, or panel data. θ is the optimal value of the objective function; λj is the optimal solution. To further analyze input redundancy and output deficiency, slack variables s+ for inputs and $s-$ for outputs are introduced.

Based on the model, the output deficiency rate and input redundancy rate of ineffective DMUs can be further analyzed to find the direction of production adjustment and provide theoretical support to further improve industrial efficiency. The efficiency of each DMU can be evaluated using the results calculated by the CCR model. The evaluation rules are as follows:

1. If $\theta^* = 1$, and $s^{*-} = s^{*+} = 0$, DMU_{j0} is DEA efficiency. The input redundancy rate and output deficiency rate are both equal to 0, i.e., there is no input redundancy and output deficiency.
2. If $\theta^* = 1$, and $s^{*-} > or, s^{*+} > 0$, DMU_{j0} is a weak DEA efficiency, which is the presence of input redundancy or output deficiency.
3. If $\theta^* < 1, DMU_{j0}$ is DEA inefficiency; there are input redundancies and output shortfalls at this point.

When DMU_{j0} is a DEA inefficiency, its input redundancy rate and output deficiency rate can be calculated. Let this input redundancy be $\Delta x_i > 0$ and the output deficiency be $\Delta y_i > 0.s^{*-}, s^{*+}, \theta^*$ is the solution of the linear programming model, and $(\hat{x}_i, \hat{y}_i)$ is the objective value of the DEA effective for evaluated DMUs. At this point, the input redundancy Δx_i and the output deficiency Δy_i can be expressed, respectively, as:

$$\begin{gathered}\Delta x_i = x_i - \hat{x}_i = \left(1 - \theta_i^*\right) \cdot x_i + s_i^{*+} \\ \Delta y_i = \hat{y}_i - y_i = s_i^{*-}\end{gathered} \tag{2}$$

Thus, the input redundancy rate and output deficiency rate can be calculated as follows:

$$\rho_i = \frac{\Delta x_i}{x_i} = \frac{\left(1 - \theta_i^*\right) \cdot x_i + s_i^{*+}}{x_i} = 1 - \theta_i^* + \frac{s_i^{*+}}{x_i} (i = 1, 2, \cdots, n) \tag{3}$$

$$\eta_i = \frac{\Delta y_i}{y_i} = \frac{s_i^{*-}}{y_i} \; (i = 1, 2, \cdots, n)$$

In the second stage, the SFA model is used to regress first-stage performance measures against a set of environmental variables. The second stage of the SFA model allows the slack variables to be obtained from the first stage DEA [11,46]. The slack variable is used as the explanatory variable to separate the effects of environment and random error factors on the efficiency value, and the SFA regression model is constructed:

$$S_{nk} = \int_n (Z_k; \beta^n) + V_{nk} + U_{nk} \; n = 1, 2, \ldots, K \tag{4}$$

where S_{nk} is the input slack variable; Z_k is the external environmental variable; β^n is the parameter to be estimated for the external environmental variable, and $\int_n (Z_k; \beta^n)$ denotes the stochastic frontier function of the effect of environmental variables on input slack; and V_{nk} and U_{nk} denote the random error term and management inefficiency, respectively, both of which are mixed error terms. The purpose of a regression analysis is to remove the effects of environmental variables and random errors, adjust all decision units to the equivalent external environmental situation, and obtain the adjusted inputs after separating the environmental factors and random factors obtained. The adjustment formula is as follows:

$$X_{nk}^a = X_{nk} + [\max(f(Z_k; \beta^n)) - f(Z_k; \beta^n)] + [\max(V_{nk}) - V_{nk}] \; n = 1, 2, \ldots, K \tag{5}$$

where X_{nk}^a is the adjusted input variable; X_{nk} is the input variable before the adjustment; $[\max(f(Z_k; \beta^n)) - f(Z_k; \beta^n)]$ and $[\max(V_{nk}) - V_{nk}]$, respectively, represent the adjustment of external environment variables and random error terms, and all units are adjusted to the same environment.

In the third stage, the DEA-CCR model is used again to evaluate the transportation efficiency of the adjusted input indicators. As the input and output indicators are under the same external environment, the efficiency value calculated will be more accurate than the efficiency value obtained using the DEA model alone.

3.3. Evaluation of Transportation Structure

The structure of the transportation system can be described and measured mainly by the structure of technology, personnel, investment, transportation capacity, and transportation volume. The result of transportation activities is the spatial displacement of passengers or cargoes, while the transportation volume is the measurement of the final product and the final embodiment of the interaction results of transportation resources, so this paper mainly selects transportation volume to measure the structure of a comprehensive transportation system.

Transportation volume is measured by two indicators: volume and turnover. However, since the average distance of various modes of transportation varies, the size of the volume does not truly reflect the capacity of various modes of transportation, so it is difficult to accurately reflect the structure of a comprehensive transportation system through the transportation volume index. Turnover is the product of the number of passengers or tons of cargo carried and the distance traveled in a certain period [43,47,48]. Turnover reflects not only the transportation volume but also the transportation distance. It is an important indicator to reflect the quantity of transportation products. Therefore, this paper selects turnover as the measurement indicator of transportation volume [49].

Due to the different industrial characteristics of passenger and freight transportation, this paper converts passenger kilometer (*PK*) and freight turnover (*FT*) in the ratio of 10:1 and 1:1, respectively. The sum of the two is combined turnover (*CT*). The unit is 100 million-tons kilometers. The formula is:

$$CT = PK/10 + FT \tag{6}$$

Based on the above discussion, assuming that the total conversion turnover is a conversion turnover of various transportation modes A_1, A_2, ..., A_n, and there are $A = \sum_{i=1}^{n} A_i(i = 1, 2, \cdots, n)$, the proportions of various transportation modes are $P_1, P_2, \ldots, P_n$, where $P_i = A_i/A$, and $A = \sum_{i=1}^{n} A_i(i = 1, 2, \cdots, n)$. Thus, it can be concluded that the information entropy of the comprehensive transportation system structure is:

$$H = -\sum_{i=1}^{n} P \ln P_i \tag{7}$$

The level of information entropy can reflect the degree of stability of the comprehensive transportation system structure. When $P_1 = 1$, the value of information entropy is the smallest, $H_{\min} = 0$. When $A_1 = A_2 = \ldots = A_n$, $P_1 = P_2 = \ldots = P_n = 1/n$, the value of information entropy is the largest, $H_{\max} = \text{lgn}$. Additionally, information entropy will generally be between the two; a good dissipative system state should be in order and chaos [50,51].

According to the definition of equilibrium degree in the information entropy theory, combined with the above discussion of the information entropy of the comprehensive transportation structure, the structural equilibrium degree of the transportation system can be expressed as:

$$B = \frac{-\sum_{i=1}^{n} p_i \ln p_i}{\ln n} \tag{8}$$

B represents the transportation structure equilibrium degree, which is the ratio between the information entropy of the comprehensive transportation structure and the maximum information entropy, and $B \in [0, 1]$. The greater the combined equilibrium of the transportation system, the better the equilibrium of structure, the smaller the relative gap between various modes of transportation and the more reasonable the development of each mode of transportation.

3.4. Panel Vector Autoregressive Model

The panel vector autoregressive model (PVAR) was first proposed by Douglas Holtz Eakin [52]. This model follows the strengths of the vector autoregression (VAR) model proposed by Sims [53]. It does not require a causal relationship between variables in advance but rather treats each variable as an endogenous variable and analyzes the effect of each variable and its lag on the other variables in the model. The PVAR model could not only reduce the required length of time series but also capture the impact of individual heterogeneity on model parameters. The PVAR model analyzes the current and future effects of an endogenous variable on itself and other endogenous variables, thus reflecting the dynamic relationship between the variables comprehensively [54]. Love, Inessa, and Lea [55,56] and Lian and Su [57] improved the panel vector autoregressive model. In this paper, the PVAR model proposed by Love and Lian Yujun is used to select the three variables of China's transportation efficiency, transportation structure equilibrium degree, and regional economic development, which correspond to the panel data from 2011 to 2020. According to the principle of the VAR model, the PVAR model can be established:

$$y_{it} = \alpha_i + \beta_o + \sum_{j=1}^{p} \beta_j y_{i,t-j} + \mu_{it} + \varepsilon_{it}, i = 1, 2, \cdots, N, t = 1, 2, \cdots, T \tag{9}$$

where y_{it} is the explained variable and β_j is the regression coefficient; α_i is the difference between the ith individual and other individuals; μ_{it} is the time point effect of individual i; ε_{it} is the residual term that obeys the normal distribution.

4. Empirical Analysis

4.1. Sample Selection and Index Selection

Based on the previous literature and data, this study takes the three indicators of transportation employment, total road mileage, and fixed asset investment as input indicators, and the three indicators of passenger turnover, cargo turnover, and added value of the transportation industry as output indicators. The per capita disposable income of residents, the urban construction land area, and the tertiary industry share are taken as environmental indicators and shown in Table 4.

Table 4. Transportation efficiency evaluation indicators.

Type of Indicator	Name of Indicator	Unit
Input Indicators	Transportation employment (X1)	People
	Total road mileage (X2)	10,000 km
	Fixed asset investment (X3)	100 million yuan
Output Indicators	Passenger turnover (Y1)	100 million-person-km
	Cargo turnover (Y2)	100 million-ton-km
	Added-value of the transportation industry (Y3)	100 million yuan
Environmental Indicators	Per capita disposable income (Z1)	Yuan
	Urban construction land area (Z2)	Square kilometer
	Tertiary industry share (Z3)	%

4.2. Evaluation of Transportation Efficiency

According to the efficiency value of the first stage, the SFA model of Frontier 4.1 software has been used to remove the influence of environmental factors and statistical noise. Then, based on the results of the second stage SFA model, the data-adjusted transportation efficiency values were calculated for 28 provinces using DEA-SOLVER software. The transport efficiency values in the third stage are significantly different from the results of the first stage. After excluding the influence of the external environment and random interference, the transportation efficiency of most provinces increased.

In Table 5, the results show that the transportation efficiency of 28 provinces in China shows a fluctuating upward trend after excluding the influence of the external environment and random interference. It reached the highest value in 2020, and the comprehensive efficiency value of all 28 provinces will reach more than 0.96. This shows that after excluding the influence of the external environment, random interference, and other factors, the resource allocation of the transportation industry in all regions has been gradually rationalized, and various inputs have played a better role.

4.3. Evaluation of Equilibrium degree of Transportation Structure

From 2011 to 2020, the average value of the transportation structural equilibrium in China was stable and was around 0.74. This shows that from a national perspective, there is little difference in the change in China's transportation structure from 2011 to 2020. The proportion of the main transportation modes in each province is almost unchanged.

Each region developed a regional transportation industry according to its resources and advantages. The results are shown in Table 6.

Table 5. China's 28 provinces and cities' transportation efficiency values for the period 2011–2020.

DMU	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Beijing	1.000	1.000	1.000	1.000	1.000	0.961	0.915	0.912	0.958	0.962
Tianjin	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hebei	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Liaoning	0.908	0.915	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.980
Shanghai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jiangsu	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Zhejiang	0.866	0.840	0.983	0.895	0.973	0.953	0.923	0.897	0.816	1.000
Fujian	0.882	0.862	0.860	0.852	0.903	0.932	0.901	0.935	0.908	1.000
Shandong	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Guangdong	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hainan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Shanxi	0.777	0.766	0.812	0.890	0.890	0.919	0.890	0.885	0.889	0.978
Jilin	0.969	0.989	0.967	0.914	0.899	0.935	0.986	0.991	0.916	0.982
Heilongjiang	0.743	0.875	0.947	0.987	1.000	0.991	0.962	0.984	0.913	0.987
Anhui	1.000	1.000	1.000	1.000	1.000	1.000	0.930	0.902	0.922	0.983
Jiangxi	0.889	0.972	0.896	0.858	0.859	0.902	0.944	0.925	0.919	1.000
Henan	0.915	0.895	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hubei	0.845	0.838	0.776	0.787	0.819	0.836	0.850	0.852	0.848	0.959
Hunan	0.841	0.812	1.000	1.000	1.000	1.000	1.000	1.000	0.989	0.981
Neimenggu	0.995	1.000	0.912	0.958	0.988	0.981	0.924	0.955	0.995	1.000
Guangxi	0.930	0.945	0.926	0.898	1.000	1.000	1.000	1.000	1.000	1.000
Chongqing	0.803	0.775	0.751	0.791	0.833	0.787	0.748	0.735	0.751	0.969
Sichuan	0.784	0.717	0.646	0.599	0.767	0.739	0.696	0.686	0.691	0.966
Guizhou	0.970	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Yunnan	0.840	0.842	0.865	0.838	0.850	0.882	0.859	0.911	0.893	0.977
Shaanxi	0.857	0.941	1.000	0.757	0.772	0.823	0.829	0.806	0.820	0.981
Gansu	0.942	0.899	0.895	0.907	0.959	0.969	0.935	0.981	0.989	1.000
Qinghai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Average	0.920	0.923	0.937	0.926	0.947	0.950	0.939	0.941	0.936	0.989

Table 6. China's 28 provinces and cities' transportation structure equilibrium values for 2011–2020.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Beijing	0.210	0.640	0.630	0.650	0.680	0.730	0.660	0.650	0.820	0.820
Tianjin	0.300	0.380	0.700	0.660	0.770	0.800	0.870	0.880	0.890	0.910
Hebei	0.770	0.750	0.750	0.750	0.740	0.730	0.730	0.720	0.730	0.730
Liaoning	0.840	0.800	0.790	0.780	0.740	0.740	0.750	0.840	0.880	0.960
Shanghai	0.080	0.080	0.120	0.090	0.080	0.080	0.070	0.060	0.120	0.100
Jiangsu	0.660	0.630	0.590	0.590	0.670	0.700	0.670	0.690	0.720	0.700
Zhejiang	0.570	0.550	0.520	0.500	0.500	0.520	0.540	0.520	0.520	0.520
Fujian	0.650	0.630	0.630	0.600	0.560	0.540	0.530	0.510	0.440	0.420
Shandong	0.880	0.820	0.790	0.760	0.750	0.770	0.770	0.770	0.800	0.810
Guangdong	0.740	0.670	0.710	0.570	0.560	0.470	0.420	0.430	0.360	0.350
Hainan	0.300	0.290	0.460	0.260	0.300	0.320	0.390	0.410	0.180	0.090
Shanxi	0.930	0.940	0.940	0.950	0.970	0.970	0.980	0.980	1.000	1.000
Jilin	0.990	0.970	0.940	0.890	0.840	0.850	0.890	0.890	0.890	0.890
Heilongjiang	0.990	1.000	1.000	0.990	0.640	0.980	0.990	0.650	1.000	0.740
Anhui	0.710	0.680	0.820	0.790	0.830	0.820	0.820	0.810	0.800	0.790
Jiangxi	0.720	0.650	0.610	0.580	0.580	0.570	0.560	0.530	0.610	0.570
Henan	0.680	0.660	0.790	0.760	0.780	0.780	0.790	0.790	0.840	0.820
Hubei	0.980	0.970	0.960	0.930	0.920	0.900	0.910	0.910	0.930	0.920
Hunan	0.860	0.850	0.850	0.840	0.810	0.800	0.750	0.730	0.910	0.900
Neimenggu	1.000	0.990	0.980	1.000	1.000	0.990	1.000	1.000	0.980	0.980
Guangxi	0.980	0.950	0.950	0.930	0.910	0.910	0.900	0.890	0.960	0.950
Chongqing	0.790	0.760	0.800	0.770	0.760	0.750	0.750	0.760	0.720	0.740
Sichuan	0.750	0.740	0.790	0.760	0.770	0.790	0.800	0.800	0.850	0.840
Guizhou	0.650	0.680	0.710	0.700	0.710	0.710	0.700	0.680	0.740	0.730
Yunnan	0.640	0.630	0.610	0.600	0.570	0.570	0.550	0.540	0.630	0.890
Shaanxi	1.000	0.990	1.000	1.000	0.990	0.990	0.990	0.990	1.000	1.000
Gansu	0.910	0.960	0.930	0.970	0.980	0.990	0.990	0.980	0.970	0.970
Qinghai	1.000	1.000	0.990	1.000	1.000	1.000	1.000	1.000	0.900	0.880
Average	0.735	0.738	0.763	0.738	0.729	0.742	0.742	0.729	0.757	0.751

4.4. Panel Vector Autoregressive Model

4.4.1. Unit Root Test

The unit root test methods for panel data include the unit root test in the case of the same root (LLC test, Breitung test, HT test) and the unit root test in the case of a different root to avoid pseudo-regression (Fisher ADF test, Fisher PP test, HadriLM test) [58,59].

Therefore, combined with the same root and different root test methods, this paper selects the LLC test, IPS test, Fisher ADF test, and HadriLM test to test the unit root of panel data. The results are shown in Table 7.

Table 7. Unit root test.

TEST	lnTE	lnTS	lnGDP
LLC	−15.567 *** (0.000)	−17.524 *** (0.000)	−17.013 *** (0.000)
IPS	−1.268 ** (0.002)	−4.743 *** (0.000)	−2.975 ** (0.001)
HadriLM	2.943 ** (0.001)	5.139 *** (0.000)	7.638 *** (0.0000)
Fisher-ADF	4.762 *** (0.000)	4.784 *** (0.000)	2.655 *** (0.001)

Note: (1) **, ***, denote 5%, and 1%, respectively. (2) The values in parentheses in the table are *p*-values.

The results show that the original series of lnTE, lnTS, and lnGDP reject the original hypothesis at the 5% level, indicating that there is no panel unit root and that transportation efficiency (TE), transportation structure equilibrium (TS), and regional economic development (GDP) are smooth series.

4.4.2. Optimum Lag Order Selection

Before GMM estimation, the lag order of the PVAR model needs to be determined. In this paper, the order where the minimum value of the statistic is located is selected as the optimal lag order according to the AIC, BIC, and HQIC information criteria [60,61]. According to the test result, the optimal lag order is 1. Therefore, TE, TS, and GDP can be included in the PVAR model for analysis. The results are shown in Table 8.

Table 8. Optimum lag order selection.

Lag	BIC	AIC	HQIC
1	−98.85042 *	−19.42608 *	−51.70176 *
2	2.86×10^{14}	2.86×10^{14}	2.86×10^{14}
3	8.40×10^{13}	8.40×10^{13}	8.40×10^{13}

Note: * indicates the lag period recommended for the corresponding statistical indicators.

4.4.3. GMM Estimation

Given the possible time and area effects of TE, TS, and GDP, in order to eliminate the bias caused by time and area effects, this paper performs the Helmert transformation on the original variables, eliminating the time and individual effects through cross-sectional mean difference and forward mean difference. Then, TE, TS and GDP with one lag are selected as instrumental variables for generalized moments estimation, and the estimation results of the model are obtained. Here, h_lnTE, h_lnTS, and h_lnGDP denote the TE, TS, and GDP after Helmert transformation, respectively, and L1 denotes the level value at lag 1.

In Table 9, the results show that there is a positive relationship between transportation efficiency and transportation structure. It shows that there is a mutual promotion between transportation efficiency and transportation structure. The impact of regional economic development on transportation efficiency and transportation structure equilibrium is positive, indicating that economic development will promote the overall improvement of transportation levels.

Table 9. GMM estimation.

Explained Variable	Explanatory Variables	Coefficient	Std. Err.	Z	P	(95% Conf. Interval)	
h_TE	h_TE(L1.)	0.8640	0.2030	4.25	0.000	0.4650	1.2620
	h_TS(L1.)	0.1440	0.1600	0.9	0.369	−0.1700	0.4570
	h_GDP(L1.)	0.0000	0.0000	−0.13	0.895	0.0000	0.0000
h_TS	h_TE(L1.)	0.2030	0.2870	0.71	0.479	−0.3590	0.7650
	h_TS(L1.)	0.3830	0.3620	1.06	0.29	−0.3260	1.0930
	h_GDP(L1.)	0.0000	0.0000	−0.48	0.63	0.0000	0.0000
h_GDP	h_TE(L1.)	2.1305	1.2057	1.77	0.077	−0.2327	4.4938
	h_TS(L1.)	2.4336	1.6267	1.5	0.135	−0.7546	5.6219
	h_GDP(L1.)	0.7510	0.0450	16.67	0.000	0.6630	0.8390

4.4.4. Impulse Response Analysis

In order to verify the interaction relationship between variables, 200 Monte Carlo experiments were carried out with Stata17 software, and the impulse response function diagram was obtained. Through the analysis of impulse response, the results are shown in Figure 2.

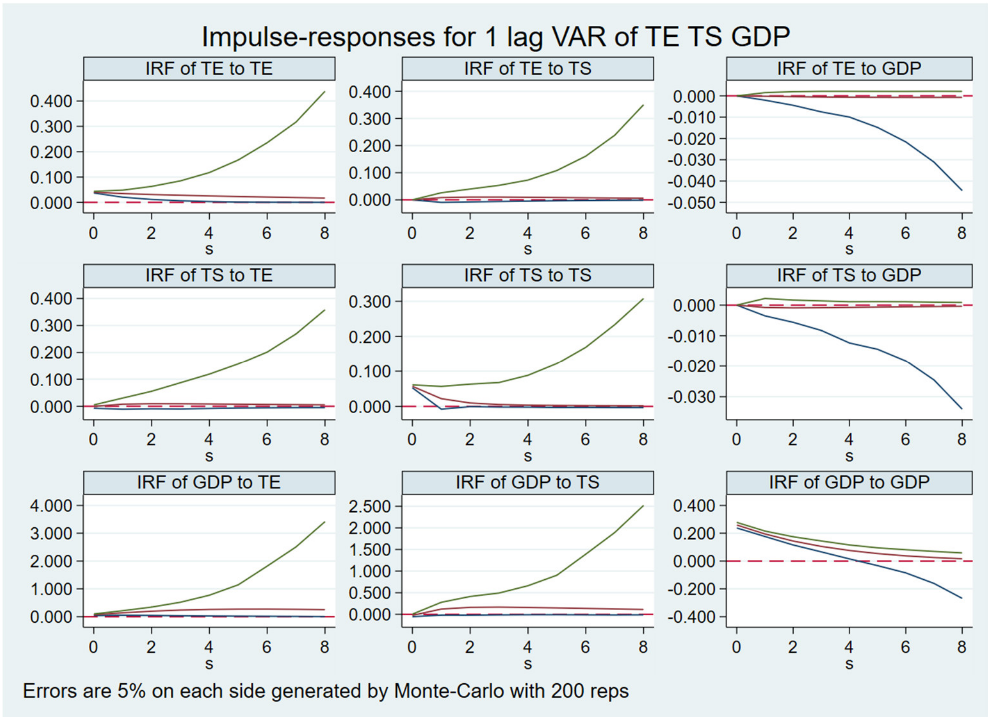

Figure 2. Impulse response function graph. Note: The green and blue lines indicate the 95% confidence interval, and the red line indicates the trend of the impulse response function.

For the TE, when impacted by the transportation structure, the impact is positive, reaching a positive maximum in phase 2 and tending to zero in phase 8, indicating that the balanced development of the transportation structure has a short-term promoting effect on the improvement of the transportation efficiency. When it is impacted by the regional economic development, it will have a continuous positive impact, reaching the maximum in the 4th period. This shows that the improvement of regional economic development has a long-term promoting effect on the improvement of transportation efficiency. When it is impacted by itself, it reaches the highest value in the current period, then gradually decreases, and tends to be stable in period 8. This shows that in the medium and short term, the improvement of transportation efficiency in the prior period can drive the improvement of efficiency in the current period.

For the TS, when the impact of transportation efficiency is received, the impact is positive, reaching a positive maximum in phase 2 and tending to zero in phase 6, indicating that the improvement of transportation efficiency has a short-term role in promoting the improvement of the equilibrium degree of transportation structure. When it is impacted by regional economic development, it will have a positive impact, reaching the maximum in the 3rd period and then gradually weakening, indicating that the improvement of regional economic development has an obvious effect on promoting the equilibrium of transportation structure. When it is impacted by itself, it reaches the maximum value in the current period and is 0 after the 3rd period, indicating that in the medium and short-term, the lag of the equilibrium degree of the transportation structure in the early period has a promoting effect on the later period.

For the GDP, when impacted by transportation efficiency, the impact is negative, indicating that transportation efficiency has a slight inhibitory effect on regional economic development. When impacted by the equilibrium degree of the transportation structure, the impact is negative and tends to 0 in period 8, indicating that the equilibrium degree of the transportation structure has a slight inhibitory effect on regional economic development. When it is impacted by itself, it reaches the positive maximum in the current period, and then gradually decreases, indicating that the regional economic development in the prior will stimulate the improvement of regional economic development in the future.

4.4.5. Variance Decomposition

In order to analyze the degree of interaction among the three variables, this paper used the variance decomposition method of PVAR to conduct a Monte Carlo simulation of 200 times with 40 periods to obtain the contribution of each impact of each variable to a certain variable. The results are as follows.

For the TE, when the variance of transport efficiency is decomposed into phase 1, it is most affected by itself, and the contribution value is 100%. With the increase in the number of periods, the equilibrium degree of transportation structure tends to be stable after the 10th period. The contribution value of the equilibrium degree of transportation structure to the transportation efficiency is 8.4%, indicating that the inertia influence of the transportation efficiency itself is particularly obvious, but the equilibrium degree of transportation structure will also affect the transportation efficiency to a certain extent.

For the TS, when the variance of the transportation structure equilibrium degree is decomposed into phase 1, it is most affected by itself, and the contribution value is 100%. With the increase in the number of periods, the transportation efficiency tends to be stable after 20 periods. The contribution value of transportation efficiency to the equilibrium degree of transportation structure is 13.2%, indicating that the inertia of the equilibrium degree of transportation structure has a great impact, but the transportation efficiency will also have an impact on the equilibrium degree of transportation structure to a certain extent.

For the GDP, when the variance of regional economic development is decomposed into phase 1, it is most affected by itself, and the contribution value is 92.5%. However, with the increase in the number of periods, the contribution of transportation efficiency and transportation structure equilibrium gradually increases. In the 30th period, the transportation efficiency and transportation structure equilibrium tend to be stable, and the contribution values are 69.1% and 18.5%, respectively. The contribution of transportation efficiency is 10 times that of phase 1, and the contribution of transportation structure equilibrium is 26 times that of phase 1. This shows that both transportation efficiency and the transportation structure equilibrium have a strong role in promoting regional economic development, in which transportation efficiency plays a leading role.

In summary, transportation efficiency and transportation structure are most affected by themselves and each other. In terms of regional economic development, the efficiency of transportation plays a leading role in the development of the regional economy, and the impact of the equilibrium of transportation structure is small.

5. Conclusions

5.1. Research Summary

Based on the previous research, this paper takes the panel data of 28 provinces in China from 2011 to 2020 as a sample to evaluate and analyze the correlation and impact of transportation efficiency, transportation structure, and regional economic development in these regions.

First, the results of the three-stage DEA model are as follows. (1) In the first stage, the overall trend of the average comprehensive transportation efficiency of 28 provinces in China from 2011 to 2020 was to increase first and then decrease. The fluctuation range of the national comprehensive transportation efficiency is small, indicating that there is a big gap in the development level of the transportation industry in various regions of China. (2) In the third stage, 20 provinces have an increasing trend in the value of comprehensive transportation efficiency. This shows that after excluding the influence of factors such as the external environment and random disturbances, the resource allocation of the transportation industry in all regions is gradually rationalized, and all inputs play a better role. (3) From the perspective of the three economic regions, transportation efficiency is highest in the eastern region, followed by the central region, and it is lowest in the western region. In the third stage, the efficiency values of the central and western regions increase significantly, which indicates that environmental variables have a great influence on the development of the transportation industry in the central and western regions.

Second, the average value of the equilibrium degree of China's comprehensive transportation structure from 2011 to 2020 is very stable, at around 0.75. This indicates that from a national perspective, the national transportation structure has not changed much from 2011 to 2020, the share of major transportation modes in each province is almost unchanged, and each region develops its regional transportation industry reasonably according to the resources and advantages of their respective regions.

Third, the results of the relationship between transportation efficiency, transportation structure, and regional economic development are as follows: (1) transportation efficiency and transportation structure have a mutual promotion effect in the short term, but both are most influenced by themselves; (2) regional economic development has a long-term role in promoting transportation efficiency and structure improvement; (3) there is a two-way promotion effect between transportation efficiency, transportation structure and regional economic development. Among them, the level of transportation efficiency plays a leading role in regional economic development.

5.2. Discussion

In previous studies on the transportation industry, transportation efficiency has been used as a separate dimension to construct studies [3,8,9,29]. In our study, we found that transportation efficiency does not fully show the development of the transportation industry. Therefore, we introduced the concept of transport structural equilibrium to compensate for the deficiency of transport efficiency in measuring the development of the industry [34,35]. The results show that the combination of transport efficiency and transport structural balance can more fully reflect the development of the transportation industry [20,33,49]. In the validation of the relationship between transport efficiency, transport structural equilibrium and regional economic development, the results indicate that transport efficiency is positively related to transport structural equilibrium, and regional economic development is positively related to the transport sector. These results support the previous study [6,62–64]. The results also provide new findings that transport efficiency plays a dominant role in regional economic development. This is supported by the empirical evidence that the efficiency level of the transportation industry is crucial to regional economic development.

5.3. Policy Recommendations

According to the current situation of each region, plans suitable for each region should be formulated to promote the coordinated development of the transportation system. From the perspective of transportation and economic development in all provinces, the overall development of the western region started late, so it is necessary to make up for its shortcomings according to its situation. The central region, as the core area connecting the east, west, north and south regions, needs to improve the channel capacity connecting the north and the south and connecting the east and the west. This should include accelerating the construction of key transportation projects in the central region and promoting the development of transportation. The eastern region needs to further optimize its transportation structure, create a synergistic transportation system, and strengthen cooperation with the central and western regions to strengthen inter-regional transportation and economic ties, enhance overall development, and enable coordinated development in all regions.

In terms of transportation efficiency, regions with unformed transportation systems need to improve their transportation development and increase investment in transportation infrastructure. Regions with more mature transportation systems should strengthen their hub functions, promote more efficient development of the transportation industry, and strengthen inter-regional cooperation to drive the reform and development of the transportation system in regions with less developed transportation systems.

In terms of transportation structure, the transportation configuration should be adjusted to reduce energy consumption and increase transportation supply. In the case of the surplus capacity of various modes of transportation, wasting resources should be avoided due to the excessive load of a single mode of transportation. In order to meet the increasing demand for transportation, it is also necessary to strengthen the reform of the transportation industry, improve the quality of all types of transportation services and optimize their organizational structure, improve the construction of comprehensive transportation hub infrastructure, and promote the reasonable and balanced development of all modes of transportation.

In terms of policy, we should avoid negative effects according to market demand. In some areas, the development of the transportation industry is too radical or seriously insufficient in the process of urbanization. In the process of policy formulation, it is necessary to fully consider the characteristics of its region and formulate its development direction. The development of transportation needs to be adjusted at any time according to social and economic development. It is not ideal to blindly pursue the equilibrium of transportation structure, which will lead to its advantages not being realized and affect economic development.

5.4. Limitations and Future Research

This paper mainly measures the transportation efficiency of 28 regions in China, analyzes the overall efficiency of the transportation industry in 28 provinces in China, and further analyzes the correlation and degree of influence between transportation efficiency, transportation structure, and regional economic development in 28 provinces in China. This paper adopts the method of empirical analysis, and the limitations mainly come from the collection and acquisition of data, the choice of research method, and the academic ability of the authors. The development of the transportation industry has promoted the development of society, but it has also created some environmental problems. Because of the limitation of data, transportation efficiency does not consider undesirable output variables. Therefore, there are some shortcomings in this paper, and we hope to further explore the following aspects in the future.

In the selection of the transportation efficiency evaluation model, the subsequent analysis can be tried by choosing the super-efficient SBM model, which considers the non-desired output. In addition to the DEA model, there are gray evaluation methods, fuzzy integrated evaluation methods, indicator evaluation methods, stochastic frontier methods, etc. There is no comparative study on these evaluation methods, so it is necessary to further analyze the advantages and disadvantages of these methods and select the most suitable evaluation method.

In the selection of efficiency evaluation indicators, only three input indicators and three output indicators were selected for the evaluation indicators of transportation efficiency. In the second stage, only three environmental variables were selected. Due to the differences in transportation environment and economy in each region, the results differed using the same residual coefficients to calculate the variables. Therefore, in future research, more reasonable evaluation indicators can be constructed in conjunction with the actual situation.

For some of the evaluation indicators selected for transportation efficiency, the data after 2020 have not yet been published and cannot completely reflect the current situation. This leads to a lack of continuity and validity of the data used in this paper, which can further deepen the study in the future.

For the indicators to measure the equilibrium of transportation structure, passenger turnover and cargo turnover are selected, and the evaluation indicators should be selected more comprehensively in future research.

In the panel vector autoregressive model, the selected variables are transportation efficiency, transportation structure equilibrium, and regional economic development. The relationship and influence of these variables have certain limitations. In future research, we can combine the previous research with the actual situation to build a more reasonable evaluation index and add some more representative variables.

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