Research on the driving factors of road freight carbon emissions based on SFA-Take Shaanxi Province as an example

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Abstract. This paper used the modified LMDI decomposition method of the stochastic frontier production function and the Tapio decoupling model to empirically analyze the driving factors and decoupling relationship of road freight carbon emissions in Shaanxi Province from 2000 to 2021. The results show that the technical efficiency of the road freight industry fluctuates wildly, which is positively correlated with the urbanization rate, the proportion of grade highways, and the industry concentration, and negatively associated with environmental regulation and the degree of opening to the outside world. Based on the above results, some suggestions are put forward to optimize the energy supply and consumption structure, improve the energy use efficiency, adjust the industrial structure, and improve the technical efficiency of the road freight industry in Shaanxi Province to promote the green and high-quality development of the road freight industry.

Keywords: CO_2 emissions from road freight, LMDI decomposition method, stochastic frontier production function, Tapio decoupling model

1 INTRODUCTION

Global warming is a common challenge for all humanity. In 2020, the Chinese government proposed achieving the "carbon peak" goals by 2030 and carbon neutrality by 2060. Carbon emissions from road freight account for 74% of China's third largest carbon emission source - transportation carbon emissions, the main body of transportation carbon dioxide emissions and the focus of energy conservation and emission reduction. Therefore, it is of great significance to calculate the carbon emissions of road freight in Shaanxi Province, clarify its influencing factors, analyze the growth law of carbon emissions, and explore the impact of various driving factors on the carbon emission reduction of road freight in Shaanxi Province, to explore the focus of low-carbon green transformation of road freight in Shaanxi Province, promote the green and low-carbon transformation of road freight, and control carbon emissions.

Standard methods used to study the drivers of energy consumption and carbon emissions include econometrics methods, Super-efficiency model based on relaxation

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measure (SBM), and decomposition analysis. As a standard method in decomposition analysis, the logarithmic mean Dirichlet exponent decomposition (LMDI) solves the problems of residual terms in the results and zero values in the data [1]. To explore more drivers, many scholars have combined decomposition models with other economic models, including Wang Wei's combination of LMDI and Cobb-Douglas(C-D) production functions, quantifying the impact of fixed assets and labor input on carbon emissions [2]. Jiang Rong achieves non-residual decomposition by calculating the critical parameters of the C-D production function, such as labor force, capital-output elasticity, and technical efficiency [3].

Existing choices of transport carbon emission impact factors focus on quantifiable variables that can reflect energy consumption, transport, economic and demographic changes [4-5]. With the rapid economic development, urbanization rate, environmental regulation, and the impact on the efficiency of transport technology, the degree of openness, industry concentration, and other indicators of increasing attention. In the present literature, when using the LMDI method to decompose the driving factors of carbon emissions, we assume that the return to scale of the production function is constant and ignore the elasticity of the actual factor output and the change of the return to scale of the road freight transport, dynamic change of technical efficiency and its influencing factors.

2 BASIC MODEL

2.1 Stochastic frontier production function model

The stochastic frontier analysis (SFA) is the deviation between the actual output and the ideal output and is a common method to measure the efficiency of production technology, which considers the influence of random factors on output, its basic form is as follows:

$$Y_t = f\left(X_t\right)\exp\left(v_t - u_t\right) \tag{1}$$

$$u_t = \delta_0 + Z_t\delta + w_t \tag{2}$$

where, Y_t, X_t denote the actual output and factor input vector, respectively. v_t, u_t denote random disturbance and technical inefficiency factors respectively, e^{-u_t} denotes production technical efficiency level, Z_t, δ, w_t represent environmental factors that affect technical inefficiency, environmental factor coefficients and random interference terms, respectively.

2.2 LMDI decomposition model of carbon emissions

The basic idea of the LMDI decomposition method is: assuming that the target variable C is the sum of j departments, and can be decomposed into the product of k driving factors, and the logarithmic average is used as the weight to achieve safe decomposition without residuals, and the additive decomposition model is as follows:

$$\Delta C_{x_k} = \sum_j W_j \times ln\frac{x_k{}^t}{x_k{}^{t-1}} = \sum_j \frac{C_j^t - C_j^{t-1}}{lnC_j^t - lnC_j^{t-1}} \times ln\frac{x_k{}^t}{x_k{}^{t-1}} \quad (3)$$

$$\Delta C_{tot} = C^t - C^{t-1} = \sum_k \Delta C_{x_k} \quad (4)$$

Where, C_j represents the target variable of department j, ΔC_{tot} represents the change of the target variable, ΔC_{x_k} is the change of the k-th driving factor.

2.3 Tapio decoupling model

The decoupling elasticity of carbon emissions and economic growth is analyzed by the Tapio decoupling model:

$$\varphi_{C,GDP_{road}} = \frac{\Delta C_t / C_t}{\Delta GDP_{road\,t} / GDP_{road\,t}} \quad (5)$$

Where, $\varphi_{C,GDP_{road}}$ represents the decoupling elasticity of road freight growth and carbon emissions. ΔC_t, $\Delta GDP_{road\,t}$ represents the change of carbon emissions and added value of road freight in the current year relative to the base year, respectively. C_t, $GDP_{road\,t}$ represent the carbon emissions and added value of road freight in the base year, respectively.

3 LMDI DECOMPOSITION AND DECOUPLING MODEL OF ROAD FREIGHT CARBON EMISSIONS BASED ON SFA

3.1 Model construction

Considering the impact of five environmental factors on the technical efficiency of road freight transport in the development process of the road freight transport industry, namely, capital input, labor input and environmental regulation, urbanization rate factor, the proportion of graded highways, the degree of openness to the outside world and the degree of concentration of the industry, this paper adopts C-D as the form of the production function, which is expressed in the following form:

$$GDP_{road\,t} = e^{\beta_0} \times K_t^{\beta_k} \times L_t^{\beta_l} \times e^{v_t} \times e^{-u_t} \quad (6)$$

$$u_t = \delta_0 + \delta_1 lnIPTI_t + \delta_2 lnUR_t + \delta_3 lnPHG_t + \delta_4 lnIR_t + \delta_5 lnR\,\&\,D_t + w_t \quad (7)$$

Based on Kaya's constant equation and combining the existing literature and the analysis of the specific situation of road freight transport in Shaanxi Province, the relationship between the carbon emissions generated by road freight transport in Shaanxi Province and the influencing factors is established, which is decomposed into the energy factor, the road freight transport factor and the economic factor.

$$C_t = \sum_j (CE_{t,j} \times ES_{t,j} \times EI_t) \times \left(PLV_t \times TAL_t \times PCV_t\right) \times \left(\frac{1}{GDP_{pc_t}} \times CTI_t \times GDP_{road\,t}\right) \tag{8}$$

The combined formulas (7) and (8) give an improved model of the LMDI decomposition method based on the SFA production function:

$$\begin{aligned} C_t &= \sum_j (CE_{t,j} \times ES_{t,j} \times EI_t) \times (PLV_t \times TAL_t \times PCV_t) \times \left(1/GDP_{pc_t} \times CTI_t \times e^{\beta_0} \times K_t^{\beta_k}\right. \\ &\left.\times L_t^{\beta_l} \times e^{v_t} \times (e^{-\delta_0} \times IPTI_t^{-\delta_1} \times UR_t^{-\delta_2} \times PHG_t^{-\delta_3} \times IR_t^{-\delta_4} \times R\&D_t^{-\delta_5} \times e^{-w_t})\right) \\ &= C_{EEt} + C_{HEt} + C_{ECt} + C_{Lt} + C_{EFt} \end{aligned} \tag{9}$$

Since the carbon emission coefficient of discounted coal and e^{β_0} are constant, and the fluctuations of e^{v_t} and e^{-w_t} are almost negligible, the energy intensity effects ΔC_{CEt}, $\Delta C_{e^{\beta_0}t}$, $\Delta C_{e^{v_t}t}$ and $\Delta C_{e^{-w_t}t}$ are all zero.

Combined with formula (6), the extended decoupling model is constructed based on the decomposition analysis of carbon emission factors as:

$$\varphi_{C,GDP_{tran}} = \left(\frac{\Delta C_{EEt} + \Delta C_{HEt} + \Delta C_{ECt} + \Delta C_{Lt} + \Delta C_{EFt}}{C_t}\right) / \left(\frac{\Delta GDP_{trant}}{GDP_{trant}}\right) = \varphi_{C_{EE}t} + \varphi_{C_{HE}t} + \varphi_{C_{EC}t} + \varphi_{C_{L}t} + \varphi_{C_{EF}t} \tag{10}$$

In the formula, the indicator for decoupling carbon emissions from economic growth can be decomposed into indicators for decoupling energy, road freight, economic, labor, and technical efficiency.

3.2 Variable selection and data description

This paper selects five driving factors (energy, road freight, economy, labor, and technical efficiency) and 15 sub-driving factors as driving factors of road freight carbon emissions in Shaanxi province; the original data in this paper are from China Energy Statistical Yearbook, national statistical yearbook, Shaanxi Statistical Yearbook, Shaanxi Traffic Statistical Yearbook and National Economic and Social Development Statistical Bulletin, the carbon emission coefficient of electric power was taken from the emission factor of northwest regional power grid in 2019, and the number of road transport enterprises in Shaanxi province was taken from the survey of Love Enterprises.

4 SFA MODEL ESTIMATION

By using Frontier4.1 software, the production function of the road freight industry results are estimated, in which $\gamma = 0.9999957$, the main parameters have passed the t-test under different significance levels. Hence, the fitting degree of the model is higher. The output elasticity of the capital factor and labor factor are 0.779 and 0.568, respectively, and they are significantly positive at the level of 1%; it is mainly driven by capital input and is in the stage of increasing returns to scale, so it is necessary to increase the input of factors of production and optimize the proportion of factors of production. As far as the technical inefficiency equation estimation coefficient is concerned, the degree of environmental regulation and opening to the outside world is significantly positive at 1% and 5%, respectively, which inhibits the improvement of the efficiency of the road freight industry, the urbanization rate, the proportion of grade highway and the industry concentration degree are significantly negative at the levels of 10%, 15%, and 1% respectively.

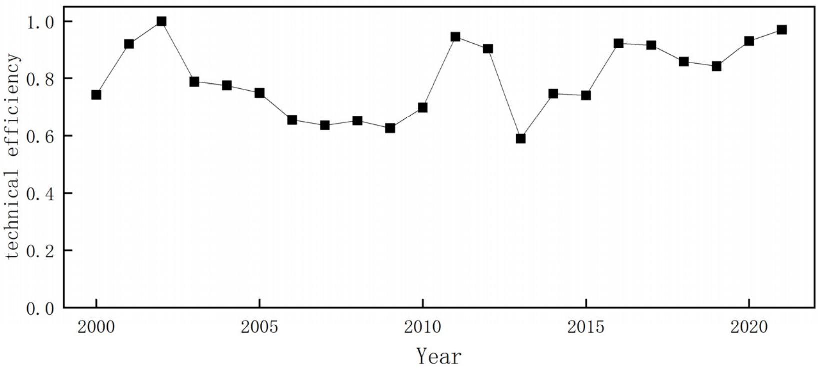

Fig. 1. Changes in technical efficiency of road freight transport in Shaanxi province, 2000-2021.

From 2000 to 2021, the technical efficiency of the road freight industry in Shaanxi province fluctuates greatly, as shown in Figure 1. The decline was evident in 2003-2009,2011-2013, and 2017-2019, with the rest of the year showing an upward trend and reaching a maximum in 2021. In order to make the road transport enterprises comply with the regulations, they should increase the investment of technological innovation and environmental protection equipment, which will lead to the increase of all kinds of investment and the increase of cost, the economic development of Shaanxi province is not highly dependent on the outside world and shows the trend of increasing first, then decreasing, then increasing again The continuous improvement of urbanization level leads to the rapid gathering of population, which will promote the expansion of trade logistics industry, pull the demand of road freight transport, and effectively promote the efficiency of road freight transport enterprises, the proportion of grade roads in Shaanxi province as a whole shows a slow upward trend, promoting the improvement of road freight transport efficiency; the industry concentration degree, that is, the proportion of large-scale enterprises in the road transport industry, shows a downward trend and the growth rate slows down, it shows that the market concentration degree of road freight industry is low, and the performance is "Small scattered weak", which inhibits the improvement of road freight efficiency.

5 EMPIRICAL ANALYSIS

5.1 Trend analysis of road freight carbon emissions in Shaanxi Province

As shown in Figure 2, Road freight carbon emissions in Shaanxi province showed a trend of first increasing and then decreasing during the sample period, fluctuating to 10,398,410 tonnes in 2018 and then dropping to 7,207,140 tonnes in 2019 due to COVID-19; the average per capita carbon emissions are in line with the trend of road freight emissions in Shaanxi province. In terms of energy composition, diesel as a significant energy source is consistent with the total carbon emissions of road freight. After 2008, the share of gasoline emissions fluctuated. With the development and promotion of new energy vehicles in 2009, the proportion of new energy vehicles, such as electric power, in Shaanxi province has gradually increased. Electricity emissions rose from a volatile 46,860 tonnes to 493,700 tonnes in 2018. However, as the number of new-energy vehicles is much lower than that of conventional petrol-powered vehicles, electricity's share of carbon emissions remains low.

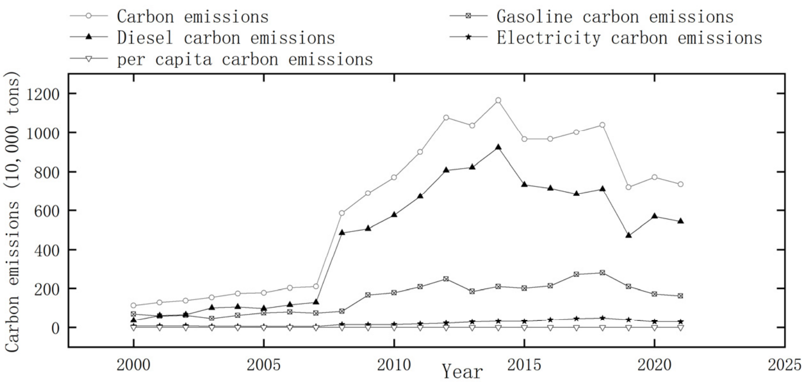

Fig. 2. Overall and structural carbon emissions from road freight transport in Shaanxi province, 2000-2021.

5.2 Analysis of road freight emission drivers in Shaanxi Province

According to the improved LMDI decomposition model, the carbon emissions of road freight transport in Shaanxi Province are decomposed by factor. The results show that the five influencing factors mentioned above have unstable influences on the direction and intensity of carbon emission reduction of road freight transport in Shaanxi

Province, and the whole, the energy factor and the economic factor inhibit the carbon emissions of road freight transport in Shaanxi Province, and the factors of road freight transport, population, and technical efficiency promote the carbon emissions.

Energy factors include energy efficiency and energy structure. Except for a few years, the energy effect value was negative, and the cumulative CO2 emission reduction was 5.3214 million tons, accounting for 16.17% of the absolute CO2 emission change of road freight transport in Shaanxi province. The effect of energy structure on the carbon emission of road freight is low, and the effect value changes from positive to negative, and the cumulative reduction increases CO2 emission by 20.01 tons; at present, there are some problems in the energy use structure of road freight transport in Shaanxi province.

Economic factors include per capita output, industry contribution, and capital input. Except for the "11th Five-Year Plan" and "13th Five-Year Plan" period, the value of the economic effect is negative. The cumulative reduction of CO_2 emissions is 7,980,300 tonnes, accounting for 24.25% of the absolute value of the change in CO_2 emissions of road freight transport in Shaanxi Province. It is the most critical factor in suppressing emissions.

Per capita output has always restrained carbon emissions, contributing 16,021,000 tons of CO_2 emissions. Except for a few years, the contribution of industry played an essential role in promoting carbon emissions, with a total of 3.076 million tons of CO_2 emissions. The contribution of capital to carbon emissions increased from 2002 to 2009 and has increased and fluctuated since then.

Road freight transport factors include freight transport service capacity, average transport route length, and truck penetration. Except for 2013, 2015, 2019, and 2021, the value of road freight effect is positive, and the cumulative promotion of CO_2 emissions is 11,002,300 tonnes, accounting for 33.43% of its absolute value, which is one of the main factors promoting emissions.

As shown in Figure 3, freight service capacity overall promotes carbon emissions, consistent with the trend of road freight CO2 emissions in Shaanxi Province in 2003, 2006, 2013, 2015, 2019,and 2021, due to the growth rate of freight turnover being smaller than the growth rate of road mileage, the corresponding years of the unit turnover of transport routes appeared to decline, resulting in fluctuations in the value of the contribution of the changes in freight service capacity to the changes in CO2 emissions However, the cumulative contribution is still positive, contributing to CO2 emissions of 6,620,100 tonnes. The average length of transport routes and the popularity of trucks have opposite influences on carbon emissions from road freight transport. The size varies over time because, except for 2006 and 2019, the road mileage, resident population, and the number of road-operated trucks grew at an average annual rate of 3.57%, 0.59% at a low and steady pace, and 9.15% at a high and fluctuating pace, respectively.

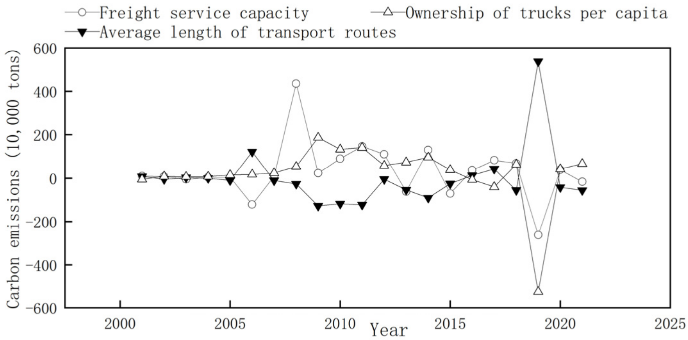

Fig. 3. Average transport routes and per capita load train ownership carbon emissions.

Because the output elasticity of the labor factor is lower than that of the capital factor, the effect of the labor factor on the carbon emission of road freight is lower than that of the capital factor. Labor input contributed to carbon emissions growth in most years, most notably in 2012,2013 and 2020, as a large number of workers entered the transport sector in 2012 and were affected by COVID-19; in order to ensure the transportation of production and living materials, the number of road freight transport practitioners has increased significantly.

As shown in Figure 4, Factors affecting technical efficiency include environmental regulations, urbanization rate, the proportion of graded roads, industry concentration, and degree of openness. The direction of the influence of technical efficiency on carbon emissions from road freight transport each year is uncertain, and the overall effect value is on the small side, showing an increasing and then fluctuating downward trend.

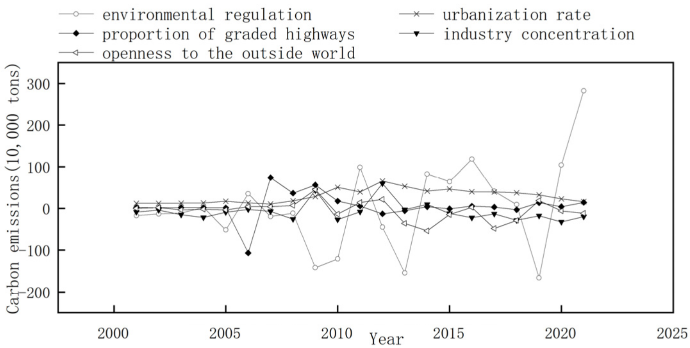

Fig. 4. Technical efficiency of carbon emissions.

The main reasons for the improvement of road freight transport efficiency to promote carbon emissions are that the improvement of road freight transport technology efficiency to achieve lower transport costs, attract more goods to road transport, the increase in urbanization rate has given rise to more demand for freight transport, resulting in a substantial increase in the volume of road freight transport; with the reduction of environmental regulations and inputs, the government's pollution control regulation intensity is lowered, and enterprises exceed the emission standards in order to make profits; the development of different grades of roads is not coordinated, and the road network connection is not coordinated. Uncoordinated development and poor road network connectivity between different grades of highways have led to traffic congestion and reduced traffic efficiency.

5.3 Analysis of the decoupling status of road freight transport in Shaanxi Province

The decoupling model calculates the correlation coefficient between carbon emissions and economic growth of road freight transport in Shaanxi Province. The decoupling coefficients of economic growth and carbon emissions of road freight transport in Shaanxi Province for the years 2001-2005, 2006-2010, 2011-2015, and 2016-2020 are measured as shown in Table 1, which indicates that the decoupling state is mainly divided into three stages: the expansion negative decoupling stage (2001-2010), the solid negative decoupling stage (2011-2015), and the decline decoupling stage (2016-2020). The decoupling status of road freight transport in Shaanxi Province is divided into three stages: the expansion negative decoupling stage (2001-2010), the solid negative decoupling stage (2011-2015), and declining decoupling stage (2016-2020), and the carbon decoupling status of road freight transport in Shaanxi Province worsens during the 12th Five-Year Plan and improves in the 13th Five-Year Plan. Improvement.

Table 1. Decoupling index and decoupling dynamics of various factors from 2000 to 2021.

Time period	Energy	Economy	Road Freight	Labor	Technology efficiency	Total decoupling Index
10th Five-Year	Strong decoupling	Strong decoupling	Expansion negative decoupling	Expansion negative decoupling	Strong decoupling	Expansion negative decoupling
11th Five-Year	Strong decoupling	Strong decoupling	Expansion negative decoupling	Strong decoupling	Expansion negative decoupling	Expansion negative decoupling
12th Five-Year	Recession decoupling	Recession decoupling	Strong negative decoupling	Strong negative decoupling	Recessive coupling	Strong negative decoupling
13th Five-Year	Recession decoupling	Recession decoupling	Weak negative decoupling	Strong negative decoupling	Strong negative decoupling	Recession decoupling

During the 10th five-year plan and the 11th five-year plan, the road freight industry in Shaanxi province expanded the scale of production by increasing the input of labor and capital factors, thus realizing extensive and extensive economic growth, in the process, the technical efficiency of road freight transport is neglected, resulting in high consumption, high emission, and low efficiency. During the 12th Five-year plan, the development of road freight entered a phase of diseconomies of scale. Road freight grew savagely with economic development and prosperity. Turnover and carbon emissions continued to rise while the value-added of road freight declined. During the 13h five-year plan, the 2018 economic crisis and the 2019 epidemic caused a sharp drop in demand for road freight and energy consumption, with the Energy and Economic Decoupling Index playing a leading role, decoupling Value Added from carbon emissions.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Research conclusion

In this paper, the stochastic frontier production function is introduced into the traditional LMDI decomposition method and the Tapio decoupling model in Shaanxi Province, based on the analysis of the effect value and stage evolution of driving factors of road freight carbon emission change in Shaanxi province, the main conclusions are as follows:

(1). The technical efficiency of road freight transportation in Shaanxi province fluctuates significantly under various environmental factors. The urbanization rate, the proportion of grade highways, and the industry concentration are positively correlated, while environmental regulation and the degree of opening to the outside world are negatively correlated.

(2). Overall, from 2000 to 2021,2021, road freight and per capita carbon emissions increased first and then decreased, eventually leveling off. Energy and economic effects restrained the growth of CO2 emissions, and road freight effects, population effects, and technical efficiency promoted the growth of CO2 emissions.

(3). The growth of the road freight industry in Shaanxi province is "expanding negative decoupling-strong negative decoupling-recession decoupling," from weak decoupling and strong decoupling to recession decoupling, labor force effect from expansion negative decoupling to negative decoupling, economic effect and technical efficiency effect of the state of decoupling constantly fluctuate.

(4). The selection of sample data needs to be further improved, and the output value and energy consumption data of the road freight industry in this paper are approximately replaced by the statistical data of the transportation, warehousing, and postal industries.

6.2 Relevant suggestions

Based on the above findings, the following policy recommendations are proposed to promote the decoupling of economic development and carbon emissions in the road freight transport industry in Shaanxi Province:

(1). As a central province of fossil energy and new energy, Shaanxi province should optimize the energy supply and consumption structure of road freight transport, increase the proportion of clean energy, and continuously optimize the structure of road transport capacity We will continue to improve the efficiency of road freight transport organizations, continue to improve energy efficiency, and bring into full play the energy structure and efficiency of road freight carbon emission reduction.

(2). The road freight industry in Shaanxi province is still in the stage of increasing returns to scale, which can be adjusted by adjusting the proportion of capital and labor input to guide industrial restructuring and upgrading optimization and promote industrial clustering; we will build an energy-saving and emission-reduction industrial structure and a green and low-carbon circular development economic system in order to achieve economic development and carbon emission reduction go hand in hand.

(3). From the perspective of the technical efficiency of road freight transport, the long-term positive impact on the efficiency of road freight transport should be realized by adjusting environmental regulations, promoting the emerging urbanization strategy with people as the core, encouraging and guiding the dangling transportation, etc. , to promote the intensive development of road freight transport industry in Shaanxi province, to promote the construction of highway infrastructure network in Shaanxi Province, to strengthen the coordinated development of different grades of highways, and to enhance the level of road network connection and transformation and circuitous connection, we should give full consideration to the level of transportation infrastructure in Shaanxi province, determine the appropriate level of opening to the outside world, improve the efficiency of road freight industry in Shaanxi province, and promote the green and high-quality development of road freight industry.

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