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Traffic Safety, Fuel Tax Intensity and Sustainable Development Efficiency of Transportation: Evidence from China

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Abstract: Negative externalities of transportation have long been a concern globally, and sustainable transportation is a shared goal among nations. Fuel taxes are regarded as an important economic means for transportation to curb fuel consumption, reduce traffic environmental pollution and realize green transportation. This study constructs a new index, Sustainable Development Efficiency (SDE), which integrates economic, environmental, and social sustainability using the Range Adjusted Measure (RAM) model of non-radial data envelopment analysis. Furthermore, the study employs the system Generalized Method of Moment (GMM) method to estimate the policy impact of diesel fuel tax on transportation SDE in China. The results indicate that a higher intensity of diesel fuel tax indirectly enhances transportation SDE in China by inhibiting the increase in truck ownership and operation in developed provinces regarding road freight transportation. Conversely, in less-developed provinces, the intensity of the diesel fuel tax can indirectly contribute to the increase in SDE by curbing the number of traffic accidents. Regional heterogeneity in SDE is evident: while western China shows potential for growth in road freight transport under the premise of ensuring environmental and social benefits, eastern China should speed up efforts to transform road freight transport into a more environmentally friendly and safer mode of transport.

Keywords: fuel tax; sustainable development efficiency; traffic safety; data envelope analysis; system GMM

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1. Introduction

The transportation industry is one of the areas with high energy consumption and high pollution worldwide. The development process of the transportation sector is accompanied by the generation of negative externalities, including air pollution, traffic congestion, and traffic accidents. The negative externalities of the transportation industry are the main obstacles to the high-quality development of the transportation industry. The huge transportation demand will stimulate more demand for energy consumption, and the negative externalities of the transportation industry will become increasingly prominent. The vast majority of transportation energy consumption is dominated by fossil fuels, and the use of fossil fuels produces a large amount of undesirable gases such as carbon dioxide (CO_2). In China, transport-related carbon emissions surged by 10.4% in 2017. The World Bank's "China Country Climate and Development Report 2022" shows that transport carbon emissions account for about 8% of China's total carbon emissions, with road transport alone contributing more than 80%.

To address these challenges, countries around the world have taken the development of green and low-carbon transportation systems as their strategic priorities [1] and actively applied various environmental regulations to control carbon emissions in the transportation sector. Fuel tax is one of the environmental regulations directly aimed at the transportation industry. Fuel tax refers to the extraction of a certain percentage from oil prices as taxes and fees in the retail process of refined oil. China's fuel tax reform began in 2009. The gasoline consumption tax was raised from CNY 0.2/L to CNY 1/L, and the diesel consumption tax was raised from CNY 0.1/L to CNY 0.8/L. At the same time, one-time charges such as road maintenance fees, transportation management fees, and government repayments of secondary highway fees were cancelled. The essence of fuel tax reform is to reflect the principle of "more use, more pay" by eliminating administration fees and increasing consumption tax rates. Fuel taxes may not have been designed for environmental purposes in the first place, but their effect is certainly environmentally friendly.

Most of the existing studies recognize the effectiveness of road fuel taxes in reducing carbon emissions [2,3], but there are disputes over the policy effect of air transport fuel tax. Some scholars argue that air transport is already a highly energy-saving mode of transport, and fuel tax has limited effect on air transport emissions [4]. Experiences of several countries, such as Europe and Japan, show that if there is no high fuel tax, the carbon emissions of these countries will be much higher. Therefore, fuel tax is regarded as an important economic means to restrain fuel consumption, reduce the negative externalities of transportation, and realize the sustainable development of transportation.

However, conclusions drawn from high-tax countries with relatively high fuel tax rates may not be applicable to China's low tax-rate environment. Some scholars are concerned about the policy effects of China's fuel tax reform [5–7]. Most of these studies are based on simulation or qualitative analysis without empirical data analysis as support. Since the implementation of the fuel tax reform many years back, the questions of whether the carbon emissions of China's transportation sector has been comprehensively improved, whether it has contributed to the high-quality development of the transportation industry, and whether the transportation industry has realized the "Porter Hypothesis" have not been fully determined. In [8] empirical analysis, it was found that the gasoline consumption tax has an inhibitory effect on carbon dioxide emissions. Moreover, the emission reduction effect of gasoline consumption tax is more significant in areas with more motor vehicle ownership. When the tax is increased by CNY 1000 per ton and the number of motor vehicles in the region increases by 10% of the national average, CO_2 emissions will be significantly reduced by 0.25%. Unfortunately, this study lacks insights into impacts of fuel taxes on other modes of transport. Most of the existing literature focuses on the impact of fuel tax on the environment, but there is little research on the impact of fuel tax on road safety, and no relevant research has been found on the impact of fuel tax on the sustainable development of China's transportation.

As sustainable development gains prominence, recent studies have incorporated social indicators into the analytical framework of sustainable transportation, but most of them are limited to qualitative analysis. The social sustainability factor of transportation is a subject for further research and quantitative analysis. Unique social attributes of transportation, marked by safety concerns such as overloading, speeding, driver fatigue, adverse weather conditions, and frequent accidents, contribute to higher accident rates compared to other industries. National statistics underscore rising casualties alongside increasing traffic volumes, underscoring safety as a critical factor hindering transportation sector development. Furthermore, property losses caused by traffic accidents involve the carrier's compensation and reputation issues, so transportation not only has social attributes, but also economic attributes.

In summary, assessing transportation's sustainable development necessitates comprehensive consideration of greenhouse gas emissions and traffic accidents' adverse societal impacts to calculate efficiency accurately. This holistic approach offers a more comprehensive and objective measure of transportation sector sustainability, crucial for informing effective economic policies. Ref. [9]'s point of view coincides with this paper. Based on the concept of sustainable development, Wang uses the SBM model to jointly evaluate the environmental impact and safety issues of road transportation in OECD countries to re-measure the road transport efficiency. Unfortunately, the study did not address the issue of sustainable efficiency across the transport sector. Ref. [10] construct the sustainable total factor productivity (STFP) of transport, which comprehensively considers economic growth, environmental impact and safety issues, and measures and analyzes the sustainable development level of transport in OECD countries, but it lacks consideration of sustainable transport issues in different regions of China.

The main contributions of this paper are as follows: First, it integrates traffic safety factors into a comprehensive efficiency evaluation index system for the transportation sector, that is, SDE, measuring the sustainability of transportation in economic, environmental and social aspects. Secondly, it empirically analyzes the impact of China's fuel tax intensity on the sustainable development efficiency of transportation and discusses the comprehensive implementation effect of China's fuel tax on carbon emissions and traffic safety in the transportation sector. Finally, the mediation effect method is used to examine the mechanism underlying fuel tax intensity policy impacts.

The rest of the manuscript is organized as follows: Section 2 is a literature review; Section 3 describes the research methods and data; Section 4 provides an empirical analysis and discussion; and Section 5 presents the conclusions, policy suggestions and limitations.

2. Literature Review and Hypothesis Development

The concept of sustainable transport was first mentioned in the 1992 EU Green Paper on the Environmental Impact of Transport and has since been continuously defined and advocated over the past three decades. Sustainable transportation is generally accepted to encompass economic sustainability, environmental sustainability and social sustainability. Social sustainability in transportation means that the benefits brought by transportation are shared by all strata of society and do not harm the interests of some people. Key social indicators such as traffic congestion and road accidents play pivotal roles in evaluating its social sustainability. The existing literature discusses the analytical framework, policy and practice of sustainable transportation from different perspectives such as economy, environment and technology [11,12]. Among them, considering the sustainability of transportation from the perspective of resources and environment dominates, such as evaluating the environmental efficiency and energy efficiency of transportation [13–15]. Although these studies investigated the impact of ecological initiatives on the economic and environmental performance of economic agents, social factors were often ignored [16]. Of the three pillars of sustainable development, the social dimension is often the vaguest and least explicit attempt to characterize sustainable development. In empirical research, social aspects are ignored to some extent because they are less quantified.

Therefore, on the one hand, energy efficiency, environmental efficiency and eco-efficiency in existing research are closely related to sustainable development [17], and eco-efficiency is more regarded as the trend goal of transition to sustainable development [18] and the path to sustainable development [19]. On the other hand, Zhang et al. (2008) [19] pointed out that eco-efficiency must be combined with other indicators and tools (such as social and cultural indicators) to be a useful indicator of sustainable development. Therefore, it is necessary to comprehensively measure sustainable development from three aspects: economy, environment and society. The pursuit of high-quality development of transportation means that higher requirements have been put forward for the socially sustainable development of transportation. The increase in social costs (such as property losses in traffic accidents) brought about by the negative externalities of transportation has also been paid more and more attention. This paper provides a comprehensive evaluation of the SDE of China's transport sector, adding indicators that represent traffic safety issues, and reflecting the balance between economic, environmental and safety issues in transport.

While extensive research examines the effect of fuel tax on emission reduction and the relationship between fuel consumption and traffic safety, scant attention is given to the relationship between fuel tax and traffic safety. As we all know, compared with aviation, rail, water and other modes of transport, road transport has the largest incidence of traffic accidents. Fuel tax policies can restrain the overheated growth of road transport by curbing fuel consumption, driving the demand for road transport to cleaner and safer modes of transport such as rail transport, reducing traffic congestion and thus reducing the number of traffic accidents. Using simulations, ref. [20] have found that fuel consumption would decline from baseline by raising the existing fuel tax per gallon of gasoline, along with a reduction in deaths per vehicle miles traveled. Ref. [21] have evaluated the impact of increased transportation pricing reforms on traffic safety and found that increases in fuel taxes could significantly reduce traffic risks in addition to providing environmental benefits. If implemented to a reasonable degree based on economic efficiency (e.g., reducing congestion and recovering road and parking facility costs), these reforms are projected to reduce traffic casualties by 40% to 60% in North America. Fuel tax rates for gasoline and diesel are different in China. Diesel is mainly used for long-distance trucks, while gasoline is mainly used for operating buses and private cars. There are large efficiency differences between passenger and freight subsystems, and the policy effects of fuel taxes may also be different and need to be discussed independently. Specifically, the impact mechanism of gasoline fuel tax and diesel fuel tax on the sustainable development efficiency (SDE) of the transportation industry is different. When the diesel fuel tax increases, the cost of road freight increases, the operating truck enterprises will raise freight rates or reduce the operating routes to balance the cost, and the increase in charges may encourage shippers to choose cheaper ways such as multimodal transport, thus reducing the volume of freight on the road. The effect of the diesel fuel tax is to inhibit the growth of road freight transport, while the gasoline fuel tax is to inhibit the growth of road passenger transport and the use of fuel-guzzling private cars [22].

The implementation of fuel tax policy increases the cost of fuel consumption. Transportation enterprises may take the following countermeasures: the first way is natural emission reduction, both by reducing excess capacity to reduce costs [23]. Highway transport enterprises can reduce the operation of vehicles or operation frequency, strengthen the scheduling of cargo sources and vehicles, and improve the load rate, long-distance freight to public rail combined transport and so on. Air transport enterprises can reduce the number of flights and reduce the vacancy rate; port enterprises can also improve the load factor through resource allocation [24]. This process of cost reduction is also a process of emission reduction. In addition, since road transport is the main place where traffic accidents occur, reducing long-distance road transport can also effectively reduce the incidence of traffic accidents. But these capacity cuts may come at the expense of economic efficiency or affect transport rates [25,26]. The second way is technological progress. By improving the energy efficiency and clean production capacity of transportation enterprises, unit carbon emissions (that is, carbon emission intensity) can be reduced [27], so as to meet the needs of transportation enterprises to maintain economic development and achieve long-term emission reduction goals. However, improving the level of clean technology through independent research and development requires long-term capital investment, and it is generally difficult for SMEs to maintain such research and development expenditures. The third way is energy substitution, that is, replacing fuel vehicles with new energy vehicles, which is the fastest way to achieve green transport [28]. However, with the current endurance and carrying capacity of new energy vehicles, it is difficult to meet the needs of long-distance freight, and such vehicles are mainly used for short-distance transportation, such as for urban distribution.

In general, when the fuel tax rate reaches a certain standard, the increase in the cost of road transportation will restrain the unnecessary consumption of refined oil, reduce the overheated growth of road transportation, and reduce carbon emissions and traffic accident rates, thus enhancing the sustainable development efficiency of transportation. The specific influence mechanism is shown in Figure 1. Based on the above analysis, the following hypotheses are proposed:

Hypothesis 1. *Fuel tax intensity has a positive impact on SDE.*

Hypothesis 2. *Fuel tax intensity can increase SDE by reducing traffic accident rates.*

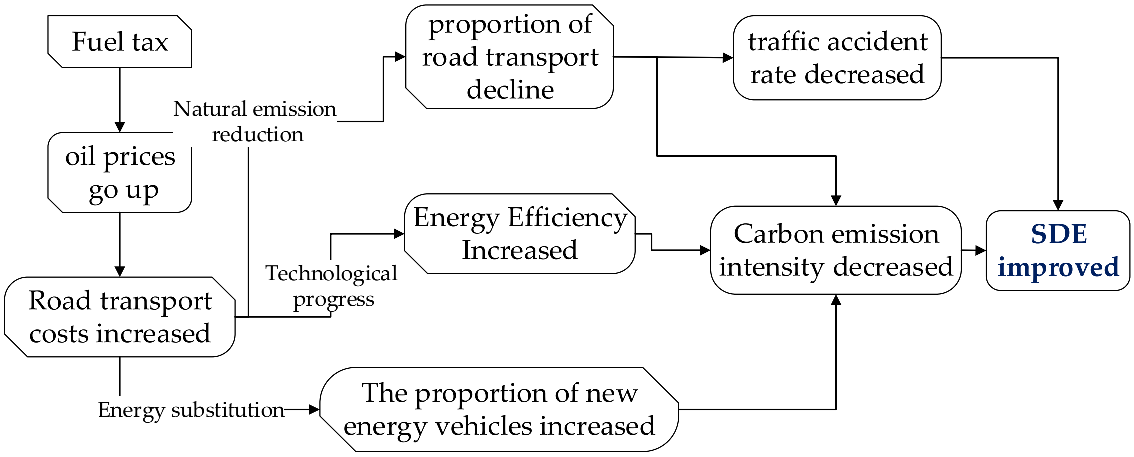

Figure 1. Mechanism of the effect of fuel tax.

There are two main methods to measure efficiency: stochastic frontier production function and data envelopment analysis (DEA). Among them, the DEA method does not need to set a specific production function, can simulate the production process with multiple inputs and multiple outputs, and has been widely used in many industries [29–31]. The non-radial DEA-SBM model is suitable for measuring efficiency problems involving unexpected outputs and is widely used in energy and environmental efficiency [32,33]. The SBM model attempts to avoid the relaxation problem and the choice of angles to solve the measurement problem of non-expected output, but it cannot avoid the inherent shortcoming of the directional distance function: due to the subjective direction vector setting, the vector set of the same decision unit in different directions is biased under the efficiency of the calculation results [34]. Sueyoshi, T. and Sekitani K. [35] have proposed the environment RAM model based on the study of [36]. This model is not only non-radial and non-angular, but also avoids the subjective setting of model parameters, and is thus more conducive to accurately measuring the comprehensive efficiency considering environmental factors. The dataset in this paper is measured by the RAM model of DEA. In the RAM model, there are two concepts: natural disposability and managed disposability. The natural disposability shows that the decision making unit (DMU) can reduce the undesirable output direction vector by reducing its input direction vector. This means that the required (good) output may be correspondingly reduced. The opposite is true for managing disposability, which means that more efficient areas can create more desirable (good) output or lower carbon emissions by improving energy efficiency [37]. However, the current international achievements in green transportation are mainly the natural emission reduction brought about by energy substitution, rather than the application and promotion of clean energy technologies in the field of transportation. In this case, the measure of sustainable development efficiency (SDE) is applicable to the RAM model under natural disposability.

3. Methods and Data

3.1. Methods

Suppose there are n districts (DMUs) in this study. The j-th DMU ($j = 1, \ldots, n$) uses a column vector of inputs (X_j) in order to yield not only a column vector of desirable (good) outputs (G_j) but also a column vector of undesirable (bad) outputs (B_j), where $X_j = (x_{1j}, \ldots, x_{mj})^T$, $G_j = (g_{1j}, \ldots, g_{sj})^T$, and $B_j = (b_{1j}, \ldots, b_{hj})^T$. λ_j indicates the j-th intensity variable. Here, the superscript "T" indicates a vector transpose. It is assumed that $X_j > 0$, $G_j > 0$ and $B_j > 0$

for all $j = 1, \ldots, n$. The RAM model for the k-th DMU under natural disposable conditions is as follows:

$$\begin{aligned}
\max \quad & \sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b \\
s.t. \quad & \sum_{j=1}^{n} x_{ij}\lambda_j + d_i^x = x_{ik},\ i = 1, \ldots, m, \\
& \sum_{j=1}^{n} g_{rj}\lambda_j - d_r^g = g_{rk},\ r = 1, \ldots, s, \\
& \sum_{j=1}^{n} b_{fj}\lambda_j + d_f^b = b_{fk},\ f = 1, \ldots, h, \\
& \sum_{j=1}^{n} \lambda_j = 1, \\
& \lambda_j \geq 0\ ,\ j = 1, \ldots n,\ d_i^x \geq 0,\ i = 1, \ldots, m, \\
& d_r^g \geq 0,\ r = 1, \ldots s,\ d_f^b \geq 0,\ f = 1, \ldots, h.
\end{aligned} \tag{1}$$

where $d_i^x (i = 1, \ldots, m)$ is the slack variable of the input variable i, $d_r^g (r = 1, \ldots, s)$ is the slack variable of the expected output r, and $d_f^b (f = 1, \ldots, h)$ is the slack variable of the undesired output f. $\overline{x}_i = \max_j\{x_{ij}\}$ and $\underline{x_i} = \min_j\{x_{ij}\}$ are defined as upper and lower bounds for all i input variables. The upper and lower bounds of the input and output determine the range R. The adjustment range for all inputs i is $R_i^x = 1/[(m+s+h)(\overline{x_i} - \underline{x_i})]$. Similarly, the adjustment range of expected output r is $R_r^g = 1/[(m+s+h)(\overline{g_r} - \underline{g_r})]$, and the adjustment range of undesired output f is $R_f^b = 1/[(m+s+h)(\overline{b_f} - \underline{b_f})]$.

The sustainable development efficiency can be expressed as follows:

$$SDE(x, g, b) = 1 - \left(\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b\right) \tag{2}$$

Here, all slack variables are determined by the optimality of Formula (1), which represents a level of inefficiency under natural disposability. The *SDE* is a unified efficiency determined by subtracting the unified inefficiency level from the unity, as shown in Equation (2) [38,39]. The measurement in this paper is performed using Matlab 2018b software.

3.2. Data and Variables

In this paper, three input indicators, one desired output indicator and two undesirable output indicators are used to evaluate the efficiency of sustainable development. The three inputs are labor, capital and energy consumption. The investment in fixed assets of transport (2006 constant CNY) is chosen as the indicator of capital; labor is expressed by the number of persons employed in transport; energy consumption is measured by the total standard coal equivalent (TCE) from coal, oil, natural gas and electricity consumed by transportation. Conversion turnover rather than the gross national product (GDP) of transport is chosen as the desired output. The converted turnover is obtained by multiplying the passenger turnover by the corresponding conversion factor and superimposing the freight turnover. The undesirable outputs are carbon emissions and direct property loss from traffic accidents. There are three indicators related to traffic safety published in China's National Statistical Yearbook: the number of traffic accident deaths, the number of traffic accidents, and the direct property loss of traffic accidents. The former two cannot comprehensively summarize the impact of traffic accidents on society, so the direct property loss of traffic accidents is chosen as the undesired output index.

Among the expected output indicators to measure SDE, the proportion of freight turnover in road transport is much larger than that of passenger turnover, and the impact will be more significant. Therefore, this paper chooses to use diesel fuel tax, which is more correlated with SDE, as the indicator of fuel tax. The fuel tax rate in China is unified, so it is impossible to conduct panel data regression analysis with the same data of 30 provinces.

In addition, the consumer's expenditure on fuel is determined by the market fuel price (barrel) and fuel tax. Therefore, the inhibitory effect of fuel tax rate on fuel consumption will also be affected by the fluctuation of oil price. The fuel tax rate is generally a stable indicator, but the fuel market price is unstable, and the fuel price in China will be adjusted according to the changes in the international market. When prices are high, they depress fuel consumption. Conversely, low oil prices could boost fuel consumption. To analyze the effect of fuel tax rates on SDE, the effect of oil prices on sustainability efficiency should be stripped out. Therefore, referring to the practice of [40], we use fuel tax intensity as the proxy variable of fuel tax policy, that is, the ratio of fuel tax rate to retail price of refined oil products (unit is %). The retail price of refined oil products is different in different regions, so the fuel tax intensity is also different, which solves the problem of not being able to perform regression analysis. We choose the highest retail price of refined oil products (CNY/L) as the indicator of oil price, and the data are from CEIC database. The price of refined oil products will be adjusted every year in line with the fluctuation of international oil prices. For the convenience of analysis, the geometric mean of retail prices in each region for each year is selected as the measure.

According to the existing literature, factors such as regional economic growth, transportation infrastructure level, energy structure and operating vehicle ownership may affect the growth of SDE of transport by affecting the economic and environmental benefits of the transportation industry. These are controlled in regression equations to eliminate interference. Panel data from all inland provinces in China (excluding Tibet) from 2006 to 2017 were sourced from the National Bureau of Statistics and China Statistical Yearbook.

4. Results and Discussion

4.1. Results

We measure the sustainable development efficiency of transportation in China's provinces from 2006 to 2017, and analyze the changing trend of sustainable development efficiency by region. Figure 2 illustrates the temporal trend of SDE in China's eastern, central, and western regions, as well as nationally.

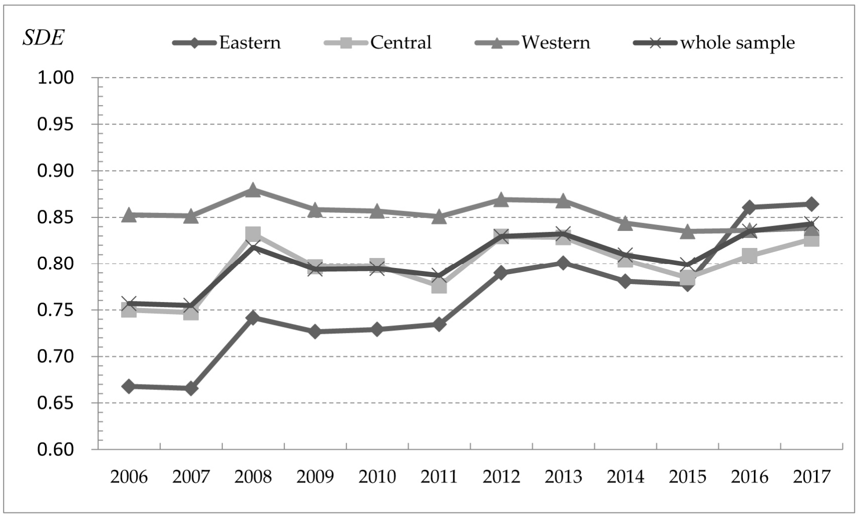

Figure 2. The trend of SDE of transport in eastern, central and western China and the whole country.

The overall average of the SDE index in China is 0.804, with the average of 0.762 in the eastern region, 0.798 in the central region and 0.853 in the western region. It can be seen that the average value of each year shows an increasing trend of "M-shaped" fluctuations. With the improvement in economic level and transportation demand, the sustainable development efficiency of China's transportation deteriorates in the short term, but with the enhancement of environmental protection and traffic safety awareness, the sustainable development efficiency is gradually improved. The SDE index of transport in the western region is higher than that in the eastern and central regions on the whole, but the regional gap has gradually narrowed in recent years, becoming very small in 2017.

4.2. Impact of Fuel Tax on SDE

Based on the New Growth Theory [41,42] and the definition of SDE, the benchmark static model is constructed as follows:

$$\ln SDE_{it} = \alpha \ln ER_{it} + \sum_{j=1}^{n} \beta_j \ln IF_{it} + \theta_i + \delta_t + \varepsilon_{it} \tag{3}$$

where *ER* represents environmental regulation, *IF* represents other factors affecting the sustainable development efficiency, θ_i represents the unobservable regional individual effect, δ_t is the time effect controlling the level of transportation development, α and β_j are the regression coefficients, ε_{it} is the random disturbance term, and $\varepsilon_{it} \sim i.id(0, \sigma^2)$ is satisfied.

Since the SDE of transport is calculated by the input–output index, the energy structure and highway operation car ownership in explanatory variables may have a two-way causal relationship with SDE, and OLS regression may lead to deviation of estimated results. The system GMM method adds the first-order difference lag term of the dependent variable to the model as the instrumental variable of the horizontal equation, which is less biased in solving the endogeneity problem. Therefore, based on the static model, we use the two-stage system GMM standard error estimation method to conduct dynamic panel regression to test the robustness of the benchmark static model. The model is constructed as follows:

$$\ln SDE_{it} = \lambda_i \ln SDE_{it-1} + \alpha \ln ER_{it} + \sum_{j=1}^{n} \beta_j \ln IF_{it} + \theta_i + \delta_t + \varepsilon_{it} \tag{4}$$

where λ_i is the influence parameter of the lagged term, and other parameters are the same as in Formula (3).

According to the above model, the environmental regulation variable here is the diesel fuel tax intensity (*DtaxI*). Since the number of operating trucks (*Veh*) has a significant correlation with other explanatory variables, this paper conducts robustness tests on this variable. The regression results are shown in Table 1. Models (1)–(3) are OLS regression with double fixed effects (FE). Model (1) discusses the influence of diesel fuel tax intensity on vehicle ownership; Model (2) discusses the influence of fuel tax intensity on the sustainable development efficiency of transportation without vehicle ownership; Model (3) discusses the influence of fuel tax intensity on sustainable development efficiency with the influence of vehicle ownership. This paper first conducts Hausman tests on the benchmark regression model (3), and the chi-square value is 33.34, which is significant at the 1% significance level.

According to the estimation results in Table 1, it can be seen that the intensity of diesel fuel tax has no significant direct impact on the improvement of transportation SDE, whether estimated through FE or system GMM. These findings suggest that the tax intensity of diesel fuel tax in China cannot promote the increase in SDE by inhibiting the effect of diesel consumption. At present, China's diesel fuel tax rate of CNY 1.2/L remains relatively low compared to international standards. In fact, during China's fuel tax reform, oil prices were in a downturn period, and increasing fuel tax did not significantly affect the volatility of oil prices for consumers or operators, nor did it reduce the added value of the transportation industry. Therefore, the fuel tax reform is smooth and excessive, and has little impact on consumer welfare, so it has not brought significant fluctuations to the sustainable development efficiency of transportation.

Table 1. The effect of diesel fuel tax intensity.

Variables	FE			System GMM		
	(1) *lnVeh*	(2) *lnSDE*	(3) *lnSDE*	(4) *lnVeh*	(5) *lnSDE*	(6) *lnSDE*
L.lnSDE					0.500 *** (4.18)	0.424 ** (2.20)
lnDtaxI	2.061 ** (2.11)	−0.339 (0.54)	−0.152 (0.24)	−0.232 *** (4.55)	−0.311 (−0.37)	0.003 (0.12)
lnVeh			−0.091 ** (2.51)			−0.050 * (−1.66)
lnAGDP	0.325 * (1.77)	−0.662 *** (5.54)	−0.632 *** (5.31)	−0.724 *** (2.98)	−0.409 ** (−2.46)	−0.494 * (−1.77)
$(lnAGDP)^2$	−0.567 *** (7.67)	0.207 *** (4.32)	0.155 *** (3.00)	0.405 *** (2.71)	0.217 ** (2.44)	0.259 * (1.67)
lnES	0.243 ** (1.98)	0.005 (0.06)	0.027 (0.34)	−0.033 (0.30)	−0.114 * (−1.66)	−0.139 * (−1.76)
lnRoadD	−0.388 *** (−2.42)	−0.217 ** (2.09)	−0.252 ** (2.42)	−0.073 (1.34)	−0.064 *** (−4.08)	−0.055 * (−1.84)
lnCI	0.147 *** (4.65)	−0.237 *** (11.61)	−0.224 *** (10.69)	−0.061 (2.21)	−0.121 *** (−5.76)	−0.135 *** (−3.86)
Constant	1.620 (1.33)	0.924 (1.17)	1.071 (1.36)	0.990 * (1.77)	1.738 (0.66)	0.973 ** (2.22)
R^2	0.843	0.493	0.480			
Control	Yes	Yes	Yes	Yes	Yes	Yes
AR(2)				0.487	0.393	0.515
Sargan				0.021	0.000	0.000
Hansen				0.248	0.284	0.085
F	233.30	30.33	18.59			
Wald chi^2				6261.08	1467.71	440.70
N	360	360	360	360	330	330

Note: t/z statistics are shown in brackets; *** represents a significant level of 1%, ** 5%, * 10%.

Regional economic growth level (*AGDP*) has a significant negative impact on the improvement of the province's SDE, while its square term has a significant positive impact on the growth of the province's sustainable development efficiency. This shows that the relationship between China's economic growth and the sustainable development efficiency of transportation is an inverted U-shaped curve, and China is still at the left end of the inverted U-shaped curve. This means that with the growth of the regional economy, the improvement of SDE will be inhibited. The density of the highway network has a significant negative impact on the improvement of China's transportation SDE. The higher the density of the highway network, the more developed the road transport business is, the more convenient the goods organization is, and the more that people will choose road transport. Under the same transport capacity, road transport is the worst in terms of safety, energy saving and environmental protection compared with rail, water and other modes of transportation. Therefore, a developed road transport network will inhibit the improvement of SDE. Carbon emission intensity (CI) also has a significant negative impact on the improvement of transportation SDE, while the energy structure has no significant impact on the improvement of the province's SDE.

According to Models (4)–(6), after solving the problem of endogeneity, diesel fuel tax intensity has a significant negative impact on the ownership of highway operational trucks, and the ownership of highway operational trucks has a significant negative impact on the improvement of China's transportation SDE. According to the research of [3], traffic accidents contribute the most to the external cost of transportation and fuel tax. The impact of diesel fuel tax intensity on the ownership of kilometer operational trucks is not only conducive to reducing the energy consumption and environmental pollution of transportation, but also conducive to reducing the number of traffic accidents. Therefore, diesel fuel tax intensity can indirectly promote the improvement of China's transportation SDE by inhibiting the growth in ownership of highway operational trucks.

Considering that the dependent variable is not objective statistical data, this paper conducts a robustness test on the dependent variable by changing the measurement index of traffic safety, which uses the number of traffic accidents to replace the direct property loss of traffic accidents, and re-measures the efficiency of sustainable development of transportation based on the SBM model, named *SDE2*. Then, regression is carried out as the dependent variable. The results are shown in Table 2. It is found that there is no significant difference in the regression results for diesel fuel tax intensity. Therefore, it can be inferred that the estimated results for diesel fuel tax intensity and operating vehicle ownership are robust.

Table 2. Robustness test of diesel fuel tax.

Variables	FE			System GMM		
	(1) ***lnVeh***	**(2)** ***lnSDE2***	**(3)** ***lnSDE2***	**(4)** ***lnVeh***	**(5)** ***lnSDE2***	**(6)** ***lnSDE2***
L.lnSDE2					0.379 ***	0.328 ***
					(8.68)	(7.65)
lnDtaxI	2.061 **	2.347	2.125	−0.197 ***	2.259	2.992
	(2.11)	(1.65)	(1.49)	(−5.17)	(0.83)	(0.008)
lnVeh			−0.057 **			−0.270 **
			(−1.94)			(−2.13)
lnAGDP	0.325 *	−1.07 ***	−1.107 ***	−0.741 ***	−1.681 ***	−0.974 **
	(1.77)	(−4.00)	(−4.12)	(−3.00)	(−2.88)	(−2.24)
$(lnAGDP)^2$	−0.567 ***	0.170 *	0.231 **	0.471 ***	1.015 **	0.576 **
	(−7.67)	(1.83)	(1.97)	(3.08)	(3.16)	(2.45)
lnES	0.243 **	−0.145	−0.171	−0.111	0.078	−0.020
	(1.98)	(0.81)	(−0.95)	(−0.97)	(0.21)	(−0.09)
lnRoadD	−0.388 ***	−1.218 ***	−1.176 ***	−0.101 *	−0.291 **	−0.154 **
	(−2.42)	(−5.23)	(−5.00)	(−1.69)	(−2.26)	(−2.05)
lnCI	0.147 ***	−0.823 ***	−0.839 ***	−0.069 **	−0.889 ***	−0.817 ***
	(4.65)	(−17.96)	(−17.72)	(−2.05)	(−6.28)	(−7.05)
Constant	1.620	1.674	1.500	1.056 **	−7.160	−8.626
	(1.33)	(−0.94)	(0.84)	(2.19)	(−0.85)	(−1.02)
R^2	0.843	0.750	0.437			
Control	Yes	Yes	Yes	Yes	Yes	Yes
AR(2)				0.519	0.484	0.505
Sargan				0.033	0.000	0.002
Hansen				0.171	0.406	0.247
F	233.30	35.83	16.5			
Wald chi^2				5772.17	2174.72	1056.75
N	360	360	360	360	330	330

Note: t/z statistics are shown in brackets; *** represents a significant level of 1%, ** 5%, * 10%.

Different regional development levels and economic structures may affect the improvement of transportation SDE. In order to discuss regional differences, this paper divides 30 provinces in China into three regions: eastern, central and western regions according to the standards of the National Bureau of Statistics for group discussion. Since the sample size after grouping does not meet the minimum sample size condition of GMM, the analysis can only be conducted by OLS with bidirectional fixed effect. In order to test the robustness of the regression results for fuel tax intensity and vehicle ownership in the model, this study refers to the existing literature and indicators of sustainable development efficiency, and adds an indicator reflecting traffic safety as a control variable, which is measured by the number of accidents (*NAcci*). However, the influence of energy structure (*ES*) on sustainable development efficiency (SDE) is always insignificant, so this control variable is removed. Since the effect of gasoline fuel tax policy is insignificant, only diesel fuel tax is discussed here, the same below. The group regression results are shown in Table 3.

Table 3. Results of regional heterogeneity analysis.

Variables	East		Central		West	
	(1) *lnSDE*	(2) *lnSDE*	(3) *lnSDE*	(4) *lnSDE*	(5) *lnSDE*	(6) *lnSDE*
lnDtaxI	1.333 (1.26)	1.626 (1.26)	2.716 (0.65)	5.353 (1.24)	−0.757 (−0.75)	−1.270 * (−1.72)
lnVeh	−0.174 ** (−2.33)	−0.262 ** (−3.75)	0.040 (0.93)	0.027 (0.64)	0.069 ** (2.37)	0.064 ** (2.46)
lnAGDP	−0.636 (−1.64)	−1.085 *** (−2.74)	0.127 (0.69)	0.114 (0.62)	−0.458 *** (−6.53)	−0.363 *** (−4.97)
$(lnAGDP)^2$	0.035 (0.21)	0.110 (0.72)	−0.405 ** (−3.02)	−0.435 ** (−3.27)	0.106 ** (2.39)	0.078 ** (1.92)
lnRoadD	0.157 (0.51)	−0.165 (−0.58)	−0.301 ** (−2.59)	−0.200 * (−1.68)	−0.033 (−0.5)	−0.083 (−1.42)
lnCI	−0.336 *** (−8.01)	−0.370 *** (−8.67)	−0.138 *** (−6.61)	−0.135 *** (−6.68)	−0.067 *** (3.49)	−0.056 *** (−3.24)
ln_NAcci		0.266 *** (4.49)	2.716 (0.65)	−0.044 ** (−2.43)		−0.059 *** (−5.27)
R^2	0.591	0.654	0.677	0.714	0.501	0.617
control	Yes	Yes	Yes	Yes	Yes	Yes
F	19.43	15.04	9.56	5.63	14.63	12.22
N	132	132	96	96	132	132

Note: t/z statistics are shown in brackets; *** represents a significant level of 1%, ** 5%, * 10%.

It can be seen from Table 3 that in the eastern and central regions, fuel tax intensity has no significant impact on the improvement of transportation SDE in the region, while in the western region, fuel tax intensity has a negative impact on the improvement of transportation SDE. This shows that the increase in fuel tax inhibits the development of transportation in the region. From the perspective of energy consumption, after the implementation of the fuel tax policy in 2009, the proportion of oil consumption in total energy consumption in western provinces such as Sichuan, Shaanxi and Shanxi has been declining. Shaanxi's share fell by 7 percent from 2009 to 2017, and Inner Mongolia's by 18 percent. The eastern provinces such as Shanghai have not changed much, and have maintained a high proportion of about 98%, while the proportion of oil consumption in Beijing has not decreased. This shows that developed regions have a large amount of fuel consumption, which is difficult to inhibit with the current fuel tax policy. It is further understood from Table 3 that the ownership of operating trucks in the eastern region has a significant negative impact on the improvement of SDE, and has no impact in the central region, while the ownership of operating trucks in the western region has a significant positive impact on the improvement of SDE. According to the data of the ownership of operating trucks in various regions, the ownership of operating trucks in the provinces of the eastern region is generally high, the eastern region is in the middle, and the ownership of operating trucks in the western region is relatively small. Therefore, it can be inferred that only when the ownership of operating trucks reaches a certain scale, the negative effect (environmental pollution and traffic accidents) will be higher than the positive effect (economic growth), thus inhibiting the improvement of transportation SDE on the whole. Therefore, the current number of operating trucks in the western region still has room to continue to grow within the scope of the sustainable development goals.

4.3. Further Discussion

The above analysis concluded that the diesel fuel tax intensity can indirectly promote the growth of SDE by inhibiting the growth of operating trucks, but the operating trucks may have an inhibitory effect on the improvement of sustainable development efficiency after reaching a certain scale. In order to further verify this conclusion, it is necessary to discuss the impact of the ownership of operating trucks under different scales and the diesel fuel tax intensity on the improvement of sustainable development efficiency. According to national statistics, the ownership of operating freight cars in various provinces in China is quite different in scale. Hainan, Qinghai, Xinjiang and Beijing and other provinces and municipalities have a low number of operating freight cars, less than 200,000, while Henan, Hebei, Shandong and other provinces have developed road transport, and the ownership of operating trucks is more than 900,000. Since the ownership of operating trucks is increasing every year, and the growth trend of vehicles in various provinces is different, it is impossible to set a fixed threshold to group. This chapter adopts the binary classification method for grouping, that is, the average of the national annual operating trucks ownership is taken, and the provinces with the ownership of operating truck less than or equal to the average are assigned the value of Scale = 1; the provinces with ownership greater than the average are assigned the value of Scale = 2. Here, the grouping situation of each year is dynamic. Grouping regression was performed with Scale as the grouping variable, and the results are shown in Table 4.

Table 4. Scale difference of diesel fuel tax policy effect.

Variables	**Scale = 1**			**Scale = 2**		
	(1) *lnVeh*	**(2) *lnSDE***	**(3) *lnSDE***	**(4) *lnVeh***	**(5) *lnSDE***	**(6) *lnSDE***
lnDtaxI	−0.256	0.119	0.044	2.922 ***	0.481 **	0.406 *
	(−0.09)	(0.05)	(0.02)	(2.98)	(2.07)	(1.71)
lnVeh			−0.292 ***			0.025
			(−4.15)			(1.45)
lnAGDP	0.459 *	−1.22 ***	−1.087 ***	0.370 *	−0.206 ***	−0.214 ***
	(0.95)	(−3.23)	(−3.07)	(1.72)	(−4.01)	(−4.18)
$(lnAGDP)^2$	−0.552 ***	0.509 ***	0.348 **	−0.451 ***	0.052 ***	0.063 ***
	(−2.73)	(3.23)	(2.29)	(−5.55)	(2.67)	(3.03)
lnRoadD	−0.407 *	−0.297	−0.416 **	−0.105	0.051	0.053
	(−1.67)	(−1.56)	(−2.32)	(−0.52)	(1.06)	(1.12)
lnCI	0.152 ***	−0.499 ***	−0.455 ***	0.126 ***	−0.073 ***	−0.076 ***
	(2.32)	(−9.78)	(−9.33)	(3.49)	(−8.52)	(−8.64)
ln_NAcci	0.115	0.085	0.119 **	0.023	−0.056 ***	−0.057 ***
	(1.42)	(1.35)	(2.00)	(0.69)	(−7.02)	(−7.11)
R^2	0.846	0.732	0.769	0.882	0.588	0.592
Control	Yes	Yes	Yes	Yes	Yes	Yes
F	22.19	16.10	18.49	94.94	43.41	40.16
N	139	139	139	221	221	221

Note: t/z statistics are shown in brackets; *** represents a significant level of 1%, ** 5%, * 10%.

The province with a higher level of operating truck ownership represents a more developed road freight transport in the region, so the negative externality of transportation is greater. As can be seen from Table 4, in provinces with a higher level of operating truck ownership than the average level, the level of operating truck ownership has a significant negative impact on the improvement of sustainable development efficiency of transportation; but in provinces with a level of operating truck ownership less than or equal to the mean, the level of operating truck ownership has no significant impact on the improvement of sustainable development efficiency. This verifies the previous hypothesis that the level of operating truck ownership will inhibit the improvement of sustainable development efficiency only when it has a large enough scale. In provinces with a level of operating truck ownership lower than the mean, the fuel tax intensity has a significant positive impact on the improvement of sustainable development efficiency and on the level of operating truck ownership. This result is unexpected. On the one hand, the fuel tax intensity stimulates the increase in operating truck ownership, increasing the carbon emissions pressure of the transportation industry; on the other hand, it can promote the improvement of sustainable development efficiency. It can be inferred that the fuel tax intensity cannot reduce carbon emissions by inhibiting fuel consumption, but has a positive impact on the improvement of sustainable development efficiency by inhibiting other adverse factors.

Table 4 highlights that in provinces where operating truck ownership exceeds the average, the number of traffic accidents (*NAcci*) has a significant negative impact on the sustainable development efficiency in provinces with lower levels of truck ownership. Conversely, in provinces with a level of truck ownership below the average, the impact of traffic accidents is not significant on SDE. Obviously, the impact of traffic accidents on the improvement of sustainable development efficiency is similar to the impact of diesel fuel tax intensity. Is there a certain correlation between the two? Can the diesel fuel tax intensity strengthen its positive impact on sustainable development efficiency by suppressing the number of traffic accidents? In order to test this hypothesis and identify the mechanism of the policy effect of diesel fuel tax intensity, this paper draws on the causal stepwise test regression coefficients of [43,44] to test the mediating effect and construct a recursive equation. With the passage of time and the difference in regional development, the development of transportation level, the improvement of transportation infrastructure, the improvement of traffic management system and other factors will reduce the probability of traffic accidents. In order to control these factors, this paper uses the time and regional bidirectional fixed effect model. The recursive equation group is as follows:

$$\ln SDE_{it} = \beta_1 \ln DtaxI_{it} + \lambda_1 \ln Control_{it} + \alpha_i + \theta_t + \varepsilon_{it} \quad (5)$$

$$\ln NAcci_{it} = \beta_2 \ln DtaxI_{it} + \lambda_2 \ln Control_{it} + \alpha_i + \theta_t + \varepsilon_{it} \quad (6)$$

$$\ln SDE_{it} = \beta_3 \ln NAcci_{it} + \lambda_3 \ln Control_{it} + \alpha_i + \theta_t + \varepsilon_{it} \quad (7)$$

$$\ln SDE_{it} = \beta_4 \ln DtaxI_{it} + \beta_5 \ln NAcci_{it} + \lambda_4 \ln Control_{it} + \alpha_i + \rho_t + \varepsilon_{it} \quad (8)$$

where $Control_{it}$ represents the control variable that may affect the carbon emission intensity of transportation, which is the same as the control variable index in the previous article (excluding the diesel fuel tax intensity (*DtaxI*)). α_i represents the unobservable regional individual effect, θ_t is the time effect of controlling the development level of transportation, and ε_{it} is the random error term. Because the policy effect of diesel fuel tax intensity is not significant in provinces with a larger than average number of operating trucks, only provinces with a smaller than average number of operating trucks are analyzed here. The test results of the recursive equation system are shown in Table 5.

Table 5. Results of mediation effect test.

Variables	Model (5)		Model (6)		Model (7)		Model (8)	
	Coef.	***p* Value**	**Coef.**	***p* Value**	**Coef.**	***p* Value**	**Coef.**	***p* Value**
DtaxI	0.064	0.013	−4.102	0.055			0.420	0.071
NAcci					−0.055	0.000	−0.053	0.000
Control	Yes		Yes		Yes		Yes	
R^2	0.483		0.464		0.577		0.551	
N	221		221		221		221	
$\beta_2\beta_3/\beta_1$	0.354							

The results of Model (5) show that the diesel fuel tax intensity has a significant positive impact on the improvement of sustainable transportation development efficiency. The results of Model (6) show that the diesel fuel tax intensity has a significant inhibiting effect on the number of traffic accidents. According to Model (7), the number of traffic accidents will inhibit the improvement of sustainable transportation development efficiency, but the effect coefficient is small. Model (8) further tests the mediating effect of the number of traffic accidents.

The results show that, on the premise of controlling the number of traffic accidents, the diesel fuel tax intensity has a significant positive impact on the improvement of sustainable transportation development efficiency, but the regression coefficient is reduced. In conclusion, provinces with truck ownership below the average experience diesel fuel tax intensity positively impacting transportation SDE improvement, partially mediated by traffic accidents. The mediating effect size is calculated at 0.354, indicating that diesel fuel tax intensity indirectly promotes SDE by reducing the number of traffic accidents. This effect stems from a shift in transportation modes. According to the statistical data, the main body of traffic accidents is mainly motor vehicles on the highway, and the number of accidents on the railway and other modes of transport can be almost ignored. The increase in the diesel fuel tax will prompt some long-distance freight businesses to transition to rail and other modes of transport, and inhibit the overheated growth of highway freight. The reduction of the number of trucks on the expressway, especially the number of long-distance transport trucks, will significantly reduce the probability of traffic accidents.

5. Conclusions

5.1. Main Conclusions

Based on the panel data of China's transportation industry, this paper evaluates the impact of fuel tax intensity on the sustainable development efficiency (SDE) of transportation and its action path by constructing a fixed effect model and dynamic panel model, using FE estimation and the system GMM two-stage method. The main conclusions are as follows: (1) On the whole, diesel fuel tax intensity has no direct effect on the improvement of transportation SDE, but can indirectly improve the SDE of transportation by inhibiting the growth in the ownership of operating trucks. From the perspective of the action path, this does not accord with the "Porter Hypothesis". (2) In terms of regions, diesel fuel tax intensity in the eastern and central regions has no significant policy effect, while in the western region, fuel tax intensity has a negative effect on the improvement of transportation SDE and the ownership of operating trucks has a positive effect on the improvement of SDE. (3) The policy effect of diesel fuel tax intensity also shows significant scale heterogeneity. In the provinces with developed highway freight (mainly in the central and eastern regions), diesel fuel tax intensity can indirectly promote the improvement of transportation SDE by inhibiting the growth in the ownership of highway operating trucks. In less-developed areas, the diesel fuel tax intensity not only directly promotes the improvement of traffic SDE, but also strengthens the positive impact on the improvement of traffic SDE by inhibiting the number of traffic accidents.

There are some limitations in the current research that deserve further discussion. First, due to the limitation of data availability, this study did not take into account the impact of the 2020 pandemic. China's regulations during the pandemic had a relatively large impact on the transportation industry, so it may not be possible to predict the development trend of SDE after 2020. Second, we use the annual average as a threshold for binary classification, rather than a specific numerical value, reflecting the relative scale of change rather than the absolute scale. Such an assumption may result in a certain deviation from the actual threshold. The use of three-layer classification for threshold analysis will be further explored in the future.

5.2. Policy Suggestions

The research results of this paper show that, as an economic means, fuel tax can inhibit the expansion of the road transport business and the increase in traffic accidents to a certain extent, but faces difficulty in widely inhibiting fuel consumption and promoting the sustainable development of transportation. The transportation industry has not realized the "Porter's hypothesis". According to the research conclusions and the development trend of transportation, the following three policy suggestions are proposed:

(1) Control the growth in the number of operating vehicles in the eastern and central regions. At present, the fuel tax rate is low, which makes it difficult to inhibit fuel consumption. The "Porter's hypothesis" has not been realized in the transportation sector. With the decline in international oil prices, the price of private cars, and the increasing volume of logistics transportation, the fuel consumption of transportation may also experience a substantial increase. The pressure of emission reduction and road safety management in transportation will also increase. If the government hopes to restrain the fuel consumption

and carbon emissions of the transportation sector and reduce traffic accidents through fuel taxes, it should increase the fuel tax rate substantially in the eastern and central regions, but this may be at the cost of inhibiting the economic growth of the transportation sector and damaging the welfare of private car consumers. In the provinces mainly in the western region (except the municipalities directly under the Central Government) with a level of cargo truck ownership smaller than the average, there is still room for development of road cargo transportation under the premise of ensuring sustainable development goals. Conversely, in the provinces mainly in the eastern and central regions with a level of cargo truck ownership higher than the average level, the government should take appropriate administrative or economic measures to control the growth in the number of operating vehicles and restrain the overheated development of road transportation. Compared with the overall increase in the fuel tax rate, directly controlling the number of operating vehicle permits is more targeted.

(2) Actively promote the "road to railway" and reduce the level of road transportation. Road transportation is the main source of environmental pollution and traffic accident casualties. Changing the transportation structure, that is, weakening the dominant role of road transportation and guiding the transfer of road cargo to railway, waterway and other, more environmentally friendly and safer transportation modes with high scale efficiency and low carbon emissions can significantly reduce the carbon emission intensity of transportation and traffic accident casualties. An effective way to transform the transportation structure is to develop multimodal transportation. It is suggested to accelerate the pilot construction of the "backpack transportation" project in China, increase government support, improve the market competitiveness of rail transportation, and encourage a shift in the flow of goods from the road transportation market to rail transportation. At the same time, the regional governments should organize the study of advanced experience in transportation management at home and abroad, improve the control of traffic safety, improve the safety prevention and supervision mechanism of transportation, and reduce the incidence of accidents in transportation, so as to improve the efficiency of sustainable development and realize the "green catch-up" of transportation.

(3) Strengthen the development and application of new energy technologies for heavy vehicles. With the development of e-commerce and trade globalization, the demand for transportation will further increase, and it is difficult to maintain for a long time simply relying on natural emission reduction. In theory, clean energy technology and energy substitution, such as with electric or hybrid new energy vehicles, can alleviate the environmental impact of fossil fuels required for road transportation. In recent years, China's new energy vehicles have developed rapidly with the support of policies, the mileage and charging efficiency of electric vehicles have also been significantly improved, charging facilities are becoming more and more developed, and the market share of electric private vehicles is steadily growing. However, the main sources of carbon emissions in transportation are trucks and operating buses, and the emission reduction effect of private new energy vehicles is relatively limited. Therefore, the Chinese government should strengthen policy subsidies for electric trucks and electric buses, create conditions that promote the electrification of transport vehicles, and increase support for clean energy technology research and development enterprises in transportation.

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