Sustainable total factor productivity of transport: considering safety issues and environmental impacts

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Sustainable total factor productivity of transport: considering safety issues and environmental impacts

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Abstract: Economy, environment and safety are three important components of sustainable transport. This paper proposes a productivity measurement standard that comprehensively considers economic growth, environmental impact and safety issues, namely sustainable total factor productivity (STFP). We measure the growth rate of STFP in transport sector of OECD countries in terms of Malmquist-Luenberger productivity index by applying data envelopment analysis (DEA). It is found that the growth rate of total factor productivity in transport sector can be overestimated if safety is ignored. In addition, we discuss the influence of socio-economic factors on the measurement results, finding that there exists a threshold on the impact of environmental regulation intensity on the growth of STFP in transport. That is, STFP increases with environmental regulation intensity if it is smaller than 0.247, while STFP decreases if it is larger than 0.247.

Keywords: Safety, sustainable total factor productivity, data envelopment analysis, environmental regulation.

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1. Introduction

As one of the world's energy-intensive sectors, transport consumes a large amount of fossil fuels every year. The burning of fossil fuels release a large number of undesirable gases, such as greenhouse gas (GHG)，which will bring extensive environmental impacts. Furthermore, the rapid development of trade and e-commerce globalization spawned huge demand for freight. The output value of transport has been increasing, along with the increase of its negative externalities. Therefore, the sustainable development of the transport is becoming more and more urgent. Sustainable development was first proposed more than thirty years ago (WCED, 1987), and it has received increasing attentions in both academia and practice (Cameron, 1991; Cash *et al.*, 2003; Robert *et al.*, 2005). It is defined in various manners. According to the definition of WCED(1987), which is the most widely accepted definition，sustainable transport consists of three components: environmental sustainability, economic sustainability and social sustainability. Environmental sustainability requires the reduction of pollutions caused by transport and maximizing the quality of life. Economic sustainability means that transport has the capability of adapting to people's increasing needs. Social sustainability means that the benefits caused by transport are shared by all social strata without harming the interests of some people, such as traffic congestion and traffic accidents.

Total factor productivity (TFP) is regarded as the engine that drives economic growth instead of the traditional input factors. It has become an important basis for judging the high-quality development of various industries. Considering environmental protection, some scholars introduced environmental factors in the analytical framework of TFP, e.g., green total factor productivity in the range of industry (Chen, 2010; Chaofan, 2016), agriculture (Li, 2014; Coelli and Rao, 2005), etc. However, the measurement of GTFP in transport industry has not been considered in literatures. Based on the existing research, TFP will decrease if environment factors are considered, otherwise it will be overestimated. In addition, the social attributes of transport are different from those of industry and agriculture. The accident rate is much higher than other industries due to the unsafe factors, such as overloading, speeding, fatigue driving, bad weather and accidents. Statistics show that as the traffic volume increases year by year, casualties and property damage caused by traffic accidents have increased, which disrupts the social order and living conditions. Hence safety has become one of the important pillars of sustainable transport. McLeod and Curtis (2020) recognize the need to integrate road safety with broader urban sustainable transport measures. The property damage caused by traffic accidents involves the carrier's compensation for damage and the reputation of delivery. In other words, safety issues of transport have both social and economic attributes. Therefore, when measuring the sustainability of transport, it is necessary to consider the adverse impact of safety issues on society. Furthermore, it is important to jointly assess the environmental impact and traffic safety from a policy perspective. On the one hand, environmental policy affects traffic safety. For example, the new Corporate Average Fuel Economy Standards may cause consumers to choose lighter trucks, which provide less protection in accidents, which will result more road fatalities every year (Liu, 2017).The other side of it, traffic safety policies such as speed limits also affect fuel efficiency and pollutant emissions (Hosseinlou *et al.*, 2015). The environmentally friendly speed limit scheme has attracted the attention of the academic community (Killeen and Levinson, 2017; Yang *et al.*, 2021).In summary, it is reasonable and meaningful to consider economic, environmental, and safety issues when measuring the TFP of transport.

Wang (2019) are relevant to this paper. Combining with the economic, environmental and safety factors of road transport, Wang (2019) apply the data envelopment analysis method to assess the comprehensive efficiency of sustainable transport in OECD countries. . However, they only discuss the issue of efficiency, without considering TFP, i.e., the growth rate of efficiency.

In terms of environmental regulations, most of the existing literatures focus on the effectiveness of specific transport environmental regulations in a country to reduce pollutant emissions, such as carbon emission trading system(ETS)(Jiang *et al.*, 2016), emission control areas((ECAs)(Chen *et al.*, 2018; Svindland, 2018), fuel tax(Fukui and Miyoshi, 2017; Santos, 2017), carbon tax(van der Ploeg and Rezai, 2017), etc.. However, the impacts of environmental regulations on the comprehensive efficiency or total factor productivity of transport are neglected.

The main contributions of this paper are as follows: First, this paper measures TFP with consideration of environmental impact and safety factors under the framework of sustainable development,, namely sustainable total factor productivity (STFP). This measurement can accurately reflect the development status of transport system. Secondly, this paper compares the performance differences between OECD countries in the STFP index and GTFP index, and is used to discuss the advantages and disadvantages of countries in the field of sustainable transport. Countries with lower STFP index and higher GTFP index indicate less improvement in their traffic safety. Finally, the impact of the intensity of environmental regulations on the growth of STFP in transport is discussed.

The remainder of the paper is organized as follows: The second part is literature review; the third part describes the methods and data; the fourth part shows the empirical results and their implications; the fifth part concludes with discussions on the limitations.

2. Literature review

Research on sustainable development can be extended to ecological efficiency, which has been continuously proposed over the past 30 years. Ecological efficiency is considered as an effective tool for assessing sustainability because it takes into account the environmental impacts associated with economic development (Caiado *et al.*, 2017). Ecological efficiency is usually used to measure the ecological performance levels of a country or industry and to identify possible directions for improvement, or to judge the impact of ecological initiatives on a country's economic and environmental performance. Many existing studies fall into these categories. Ecological efficiency has even been seen as a trend goal for the transition to sustainable development. However, according to WCED's definition, sustainable development includes economic, environmental and social sustainability. Among these three pillars, the social dimension is usually the vaguest and least clear attempt to characterize sustainable development. In empirical studies, social factors are less quantified and hence are ignored to some extent (Surbeck and Hilger, 2014). Zhang *et al.* (2008) point out that ecological efficiency must be combined with social indicators to become a useful index of sustainable development.

Indicators for assessing social sustainability are defined differently in different areas. Existing research has used social indicators such as safety, health, education, equity and charity, many of which are considered subjective and qualitative (Hutchins and Sutherland, 2008). Dempsey *et al.* (2011) define urban social sustainability from the perspectives of social equity, social networks, and community security. They believe that a balance needs to be struck between social sustainability, economic sustainability and environmental sustainability. Yan *et al.*(2018) believe that urban sustainable development efficiency is the comprehensive efficiency of urban development between the inputs of natural resources and the outputs of the environment and human welfare, whose social indicators focus on health, education and life. Social indicators to evaluate sustainable development in the field of industry and supply chain focus on land use (Rashidi and Saen, 2018), production accident rate, corporate social responsibility, etc. Charmondusit *et al.*(2014) evaluate the social ecological efficiency of the wooden toy industry by adding three social indicators: frequency of accidents, local employment and corporate social responsibility. They point out that social indicators enable companies to achieve optimal stability, thus ensuring greater competitiveness and business sustainability. Alves and Dumke De Medeiros (2015) implicitly involve social issues when studying the ecological efficiency of micro-enterprises, and strive to pursue better economic, environmental and social performance, which can be understood as implicit social indicators.

The existing literatures discuss the analytical framework, policies and practices of sustainable transport from economic, environmental, or technical perspectives. Among them, the environment perspective is dominant, and some literature even equates sustainable transport with green transport. With the popularization of the concept of sustainable development, some papers have incorporated social indicators into the analysis framework of sustainable transport, but most of them are limited to quantitative analysis. Social indicators of transport focus on accessibility, traffic safety, traffic congestion, and noise. Robert Joumard (2010) proposes an assessment framework for sustainable development of transport by integrating economic, social, and environmental dimensions, in which social indicators are mainly accessibility, environmental equity and mobile cost. However, their research lacks quantitative analysis. Compared with other factors, the statistical data of safety issues such as traffic casualties and direct property losses are relatively easy to obtain, so they are more suitable for quantitative analysis. However, only a few studies have taken into account safety issues when assessing the efficiency of transport (Shen *et al.*, 2015). Pal and Mitra (2016) account for accidents as DEA's undesirable output in their study of the efficiency of state road transport undertakings in India. Wegman (2017) compares traffic casualties and accident rates worldwide and found that 90% of traffic casualties occurred in low-income and middle-income countries. From the perspective of sustainable development, Wang and

Sun (2019) discuss the optimization of traffic structure of historic blocks, and safety and comfort were taken as social indicators. However, these studies only assessed the impact of safety issues on transport efficiency, and few have comprehensively evaluated environmental impacts and safety issues. In sum, safety is a key indicator that needs to be paid attention to but ignored in the field of transport efficiency and TFP, and it is a subject worthy of further study.

The common measurement methods of TFP include Solow residual method (Moghaddasi and Pour, 2016), stochastic frontier approach (Kim and Shafi I, 2009) and data envelopment analysis (Coelli and Rao, 2005). DEA is a method capable of determining best practices in a set of comparable decision making units (DMUs) to form effective production boundaries. The traditional DEA-CCR (Charnes *et al.*, 1978) and DEA-BCC (Banker *et al.*, 1984) models are radial models that assume all outputs maximization. However, this assumption is inappropriate when there is an undesirable output, such as carbon emission (Lu *et al.*, 2019). Tone (2001) proposed a non-radial model based on the slacks-based measure. Zhou *et al.*(2006) included undesired output in the slacks-based measure model to construct the environmental performance index. Shi *et al.* (2010) and Sebasti *et al.*(2011) further expanded and upgraded the SBM model. With the continuous improvement and expansion of models, the measurement of efficiency considering environmental impacts has been identified as an important application area of DEA (Zhou *et al.*, 2007; Lu et al., 2019). Considering that STFP involves undesired output, it is more suitable to use DEA for measuring STFP.

Environmental regulation is formulated to curb environmental pollution and pursue sustainable development, but the relationship between environmental regulation and economic growth has always been controversial. Some literatures believe that environmental regulation will bring additional costs to enterprises, which will increase the total costs, reduce its profit, and weaken its market competitiveness (Feichtinger *et al.*, 2005). Moreover, in order to avoid the increasingly heavier pollution control costs in the future, the mining of fossil energy such as coal has been accelerated, resulting in a short-term decline in the price of fossil energy and an increase in demand, aggravating environmental pollution, resulting in a "green paradox" phenomenon. On the contrary, other researches have argued that "strict environmental regulations do not necessarily weaken competitive advantage; in fact, good environmental regulations can also guide or force companies to develop cleaner production technologies, thereby improving their technological level and corporate competitiveness. This is the famous "Porter Hypothesis"(Porter 1991).Subsequently, many scholars conducted a large number of empirical researches to test the validity of the Porter Hypothesis, and come to different conclusions on different research subjects. Lanoie *et al.*(2011) verify the validity of the" weak" version of Porter Hypothesis, that is, flexible environmental policy regime can stimulate enterprises to innovate more than normative regulations. Malin and Shuhong (2013) find that environmental regulations and technological progress have a positive impact on improving environmental efficiency. Wang *et al.* (2019)'s research on green productivity growth in the industrial sectors of OECD countries validates the Porter Hypothesis, but only if the environmental policy is within a certain level of strictness (less than 3.08), beyond which it will become an adverse effect. However, the impact of environmental regulations in transport may be difference. Chang *et al.* (2018) propose that the establishment of Emission Control Areas (ECA) has reduced the efficiency of ports in the North and the Baltic Sea. In summary, it is necessary to discuss the policy effects of OCED's environmental regulations of transport, and there is no relevant research at present.

3. Methods and data

3.1 Methods

This paper applies the slacks-based measure model to measure the sustainable development efficiency (SDE) of transport in countries. Suppose the decision-making units $DMU_j (j=1,...n)$ use inputs $x_{ij}(i=1,...,m)$ to produce desired outputs $y_{rj}(r=1,...s)$ and undesired outputs $z_{fj}(f=1,...,h)$; *m*, *s*, and *h* represent the number of inputs, desired outputs, and undesired outputs, respectively. Then the SBM model to measure the efficiency of sustainable development can be formulated as follows:

$$SDE^{*}=\min\frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{d_i^x}{x_{ij}}}{1+\frac{1}{s+h}\left(\sum_{r=1}^{n}\frac{d_r^g}{y_{rj}}+\sum_{f=1}^{h}\frac{d_f^b}{z_{fj}}\right)}$$

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

Where d_i^x (i = 1, …, m), d_r^g (r = 1, …, s) and d_f^b (f = 1... , h) are the slacks of inputs, expected outputs and non-expected outputs. The slacks in both outputs appear in the denominator of the target function. A higher d_r^g represents a lower expected output, and a higher d_f^b represents a higher undesired output, both of which lead to a reduction in the sustainable development efficiency (SDE).

To measure the change of STFP in different periods, the Malmquist-Luenberger productivity index based on the model (1) is constructed as the following formula (Chung *et al.*, 1997):

$$ML_t^{t+1}=\left[\frac{SDE^t(x^{t+1},g^{t+1},b^{t+1}\,|\,C)}{SDE^t(x^t,g^t,b^t\,|\,C)}\times\frac{SDE^{t+1}(x^{t+1},g^{t+1},b^{t+1}\,|\,C)}{SDE^{t+1}(x^t,g^t,b^t\,|\,C)}\right]^{1/2} \qquad (2)$$

Model (2) represents the change degree of sustainable total factor productivity of a DMU from period t to period t+1. If the Malmquist-Luenberger index value is greater than 1, it indicates that the productivity presents an upward trend; otherwise, it indicates a downward trend. The real value of total factor productivity is difficult to obtain. In the process of empirical research, the common approach in literature is to set the TFP of the base year to 1, and then multiply the growth rate of TFP of the previous year to estimate the TFP index of the current year. This TFP index can characterize the growth trend of STFP.

Matlab 2015b is used for calculation. In this paper, we define 2010 as the base year, that is, the STFP values for all countries in 2010 are assumed to be 1. The STFP index represents the cumulative growth rate of STFP based on 2010 in the empirical research below.

3.2 Data and variables

Transport energy consumption data comes from the International Energy Agency (IEA) energy efficiency indicator database[1], while others come from the Organization for Economic Cooperation and Development (OECD) database. We use six variables in this paper refer to three inputs, one desired output and two undesired outputs to measure the sustainable development efficiency of transport. The three inputs are: labour, expressed by the number of employed persons; capital, expressed by the investment in fixed assets of transport (2010 constant US dollar); and energy consumption, expressed by the total standard coal equivalent (TCE) consumed by freight and passenger transportation. We use the gross national product (GDP) of transport as the desired output, the greenhouse gas emissions (GHG) and road casualties as the undesired outputs. The data of road casualties include the number of injuries and deaths[2]. The descriptive statistics of input-output variables from 2010 to 2016 are shown in Table 1.

Table 1 Summary statistics of variables (2010-2016)

Variables	Units	Mean	Std. Dev.	Min	Max
GDP of Transport	US Dollar, Millions, 2010 constant	78616.47	112109.70	1951.28	543115.10
GHG emissions	Tonnes of CO_2 equivalent, Thousands	152045.50	348311.30	5479.75	1786216.00
Road casualties	Persons	125800.40	175505.90	1217	901245
Labor	Persons ,Thousands	1283.38	2106.15	8.93	8456.18
Invest	Euro constant, ten thousands	210478.30	585193.20	334.19	4191260
Energy consumption	Petajoule TCE	2861.75	7129.64	19.73	33212.50

The government usually regulates transport activities by levying fuel taxes, carbon taxes, etc. to achieve the purpose of curbing the negative externalities of transport. These

[1] Link to Energy data: http://data.iea.org/payment/products/120-energy-efficiency-indicators-2018-edition.aspx

[2] Link to Casualties data: https://stats.oecd.org/Index.aspx?DataSetCode=ITF_INV-MTN_DATA

taxes can be considered as a kind of environmental regulation of economic instruments. OECD has a database of environmental policy tools (called PINE), which was originally developed in cooperation with the European Environment Agency. The database contains detailed qualitative and quantitative information about environmental taxes, fees and charges, and environmentally motivated subsidies (OECD, 2016). The tax base covered by environment-related taxes includes: energy products (including vehicle fuels); motor vehicles and transportation services; air or water, ozone depleting substances, etc. The dataset information is classified by tax base and environmental fields, such as transport. We use data from the OECD database on the environmental tax intensity of transport sector, that is, the environment-related tax revenue per GDP of transport[3], to denote environmental regulation intensity. This paper focuses on whether the environmental regulation intensity has a positive effect on the growth of STFP in transport in various countries, so as to verify the validity of Porter Hypothesis.

4. Results and discussion

4.1. Results and ranks

We measures STFP index of transport in 25 OECD countries and China from 2010 to 2016, and ranks them with the average STFP index. In order to compare the difference between STFP and GTFP of transport, we measure the GTFP index of transport with the same models and variables, excluding road casualties. The results and ranks are shown in Table 2.

Table 2 shows that the countries with higher STFP index are Poland, Portugal and Spain, etc.; the countries with lower STFP index are Denmark, China and Netherlands, and so on. Further, we pay attention to the difference between the average GTFP index and STFP index in each country, that is, the ranking position of GTFP minus the ranking position of STFP, which is called the ranking difference (Rank Diff). We find that countries with higher GTFP indexes also have higher STFP indexes, but the situation is very different in countries with lower rankings. Among the 25 countries, the biggest decline of rankings in the STFP index compared to the GTFP index is China, which fell 23 places from second to 25th, followed by Slovak Republic and the Netherlands, both of which dropped seven places. This means that, compared with environmental impact and economic growth, the safety issues of these three countries have not been significantly improved for a long run. Because of the large population flow and frequent North-South trade activities, China's domestic road traffic flow is large. Coupled with the lack of citizens' awareness of road safety, China's road traffic accidents frequently happen. Although the carbon dioxide emission intensity of transport in China has been well controlled, its road safety problems are getting worse. More attention should be paid to strengthening the traffic safety supervision and preventing accidents.

On the contrary, the most significant rise of rankings in the STFP index compared with the GTFP index are Czech Republic, United States, and Germany, whose rankings have risen by 8, 7, and 6 places respectively. Positive differences in rankings mean that

[3] Link to ERI data:: https://stats.oecd.org/Index.aspx

traffic safety conditions in these countries are improved faster than environmental impacts. Although the United States is a large country in terms of highway fuel consumption and carbon emissions, its highway infrastructure is complete, and the incidence of traffic accidents has gradually decreased. Its experience in traffic safety prevention is worth underperforming countries such as China learning.

Table 2 Ranks of STFP index and GTFP index

Country	2011	2012	2013	2014	2015	2016	Mean	Rank	GTFP		Rank *Diff*
									Mean	Rank	
Poland	1.046	1.255	1.231	1.288	1.311	1.301	1.239	1	1.287	1	0
Portugal	1.047	1.261	1.292	1.228	1.221	1.174	1.204	2	1.158	3	1
Spain	1.046	1.115	1.148	1.208	1.225	1.287	1.172	3	1.153	4	1
Sweden	1.049	1.092	1.141	1.127	1.208	1.222	1.140	4	1.070	5	1
Australia	1.018	1.042	1.080	1.111	1.173	1.174	1.100	5	1.041	9	4
Switzerland	1.079	1.065	1.060	1.073	1.073	1.087	1.073	6	1.050	8	2
Canada	1.008	1.025	1.034	1.115	1.110	1.115	1.068	7	1.058	7	0
United Kingdom	1.013	0.999	1.018	1.081	1.066	1.071	1.041	8	1.068	6	-2
Czech Republic	0.977	1.045	1.087	1.065	0.986	1.028	1.031	9	1.013	17	8
Japan	1.014	1.013	1.011	1.030	1.048	1.057	1.029	10	1.026	11	1
Italy	1.005	1.016	1.025	1.013	1.033	1.065	1.026	11	1.013	16	5
France	1.005	1.012	0.999	1.017	1.035	1.045	1.019	12	1.015	15	3
United States	1.008	1.020	1.014	1.008	1.009	1.010	1.011	13	1.006	20	7
Finland	1.024	1.027	1.004	1.002	1.002	0.994	1.009	14	1.019	13	-1
Germany	0.998	1.010	1.018	1.003	0.997	1.004	1.005	15	1.000	21	6
Hungary	1.033	1.039	1.037	0.933	0.928	1.053	1.004	16	1.013	18	2
Austria	1.016	1.021	0.952	0.982	0.986	0.992	0.992	17	1.033	10	-7
Korea	0.984	0.980	0.990	1.002	0.997	0.987	0.990	18	0.986	23	5
Luxembourg	1.013	1.006	1.004	0.975	0.961	0.942	0.984	19	1.025	12	-7
Ireland	0.979	0.966	0.971	0.990	0.997	0.987	0.982	20	0.989	22	2
Slovak Republic	0.959	0.987	0.997	1.008	0.967	0.966	0.981	21	1.016	14	-7
Greece	1.010	1.020	0.897	1.080	1.019	0.822	0.975	22	0.967	25	3
Belgium	0.984	0.986	1.000	1.019	0.902	0.928	0.970	23	0.976	24	1
Denmark	1.075	1.062	0.953	0.950	0.861	0.871	0.962	24	0.943	26	2
China	0.951	0.951	0.944	0.934	0.923	0.916	0.937	25	1.232	2	-23
Netherlands	0.998	0.918	0.829	0.727	0.649	0.683	0.801	26	1.011	19	-7

Figure 1 illustrates the trend of the average of STFP index and GTFP index. It shows that the average of STFP index from 2010 to 2011 was slightly higher than that of GTFP index. After 2012, the average of GTFP index exceeded that of STFP index and increased significantly, while STFP index was relatively stable. The gap between the two peaked in 2015. The possible reason is that with the implementation of various environmental regulations for transport, the negative impacts of the environment decreased year by year, so the GTFP of transport increased significantly. However, the number road accident casualties increased with the development of road transport, which has offset the positive impact of environmental improvement on the growth of the TFP of transport, so the STFP has not increased significantly.

As shown in Table 2, China, Slovakia and Switzerland are the main countries that cause the overall average STFP index to be significantly lower than the average GTFP index. The value of GTFP dropped significantly in 2016, possibly because the environmental governance of transport has hit a bottleneck, and it was difficult for GTFP to sustain its growth in the short term. In fact, the promotion frenzy of new energy vehicles has passed. Due to the incomplete configuration of electric vehicle charging devices in China and the cancellation of government subsidies, people no longer favour new energy vehicles. Therefore, the space for energy saving and emission reduction in road transport becomes smaller. In addition, some literature indicates that contributions of fuel tax to energy conservation and emission reduction are limited in various countries. Environmental impacts are still major challenges for transport.

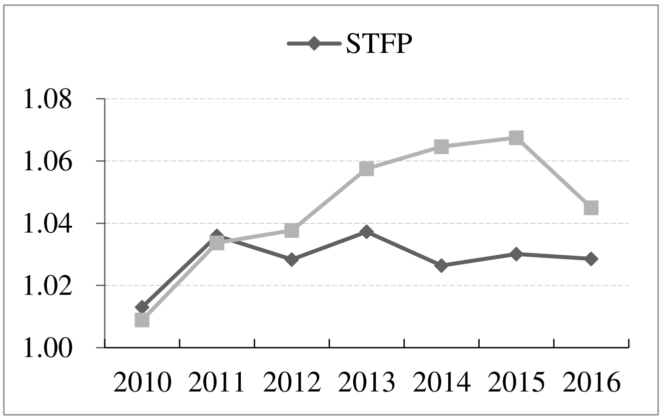

Figure 1 Trends in the average of STFP index and GTFP index

4.2 Impact of environmental regulation on STFP

Better governance performance has been associated with lower traffic accident rates (Gaygısız, 2010) and better environmental performance (Gallego-Alvarez *et al.*, 2014). Therefore, governance performance is also a key factor that is concerned in this study. The Worldwide Governance Indicators (WGI) project reports on overall governance and individual governance indicators in more than 200 countries and regions during the period 1996-2018, covering six aspects of governance [4]. Estimates of governance performance vary from -2.5 (weak) to 2.5 (strong). This article selects the estimated value of regulatory quality as a governance performance indicator related to transport for discussion.

According to the literatures, STFP may also be affected by the following factors. Income and diesel prices may affect consumer choices of travel modes (Lindgren and Stuart, 1980; Leung *et al.*, 2019) and the choice of modes of freight (Sorrell and Stapleton,

[4] Link to Governance data: http://info.worldbank.org/governance/wgi

2018), which may affect the sustainability of transport. The improvement of urbanization will promote the development of transport, but also bring greater challenges to urban ecological environment (Liu *et al.*, 2018; Giles-Corti *et al.*, 2016). Among the independent variables, *Urban* denotes the proportion of the urban population to the total population. *lnAGDP* denotes the logarithm of GDP per capita, which is used to describe the level of income. *Diesel* denotes the retail price of diesel. Data for those variables come from the World Bank. The data on retail prices of diesel is published every two years. . For the convenience of analysis, the mean interpolation method is adopted to interpolate the diesel retail price to obtain the balance panel data.

Based on the New Growth Theory and the definition of STFP, the benchmark static model is constructed as follows:

$$STFP_{it} = \alpha_i ERI_{it} + \beta_i IF_{it} + \theta_i + \delta_t + \varepsilon_{it} \qquad (4)$$

Where, ERI_{it} is environmental regulatory intensity of country i in year t, and IF_{it} is other factors affecting the growth of STFP. α_i and β_i are the influence parameters of ERI_{it} and other factors, respectively. θ_i is the unobservable national individual effect, and δ_t is to capture the effect of technological progress changing over time. ε_{it} is the random interference term. Similarly, we discussed the impacts of the above factors on GTFP. The regression results the two models are shown in Table 3.

Table 3 Comparison of estimation results of STFP and GTFP

Variables	Model(1) STFP		Model(2) GTFP	
	coefficients	T value	coefficients	T value
Governance	0.069	1.380	0.051	1.040
lnAGDP	0.147	1.220	0.501***	4.320
Urban	-0.022**	-2.560	0.037***	4.520
Diesel	-0.017	-0.190	0.116	1.330
ERI	-0.036	-0.34	-0.006	-0.060
Cons	1.287	1.020	-7.106***	-5.820
R^2	0.171		0.393	
F	9.610***		7.800***	
N	182		182	

Note: ** and *** represent significance levels of 5% and 1% respectively

As shown in Table 3, income and urbanization have significant positive impacts on the growth of GTFP, while environmental regulation intensity and governance performance have no significant impact on the growth of GTFP. On the contrary, urbanization has a significant negative impact on the growth of STFP considering safety issues, mainly because the increase of urbanization is accompanied by the increase of road casualties. Income has no significant impact on the growth of STFP, probably because the positive impact of income on transport GDP is offset by the negative impact on environment and safety. The results show that STFP pays attention to the trade-off between traffic safety, environmental protection and economic growth, and draws a different conclusion from GTFP.

According to Porter Hypothesis, environmental regulation may restrain economic growth in the short term, but in the long run, it will "force" the advancement of green technology to promote the growth of total factor productivity. Therefore, there may be a nonlinear relationship between the environmental regulation intensity and the growth of STFP in transport. In that case, the estimation results of environmental regulatory intensity in model (4) may be biased. On the other hand, the intensity of environmental regulation may produce some positive or negative effects when it exceeds a certain level, that is, there may be a "threshold effect". Therefore, the panel threshold model is considered for further analysis.

4.3 Further discussion

We refer to the panel threshold model proposed by (Hansen, 1999), take the environmental regulation intensity of transport as the threshold variable, and construct the panel single threshold model:

$$STFP_{it} = \alpha_1 ERI_{it} \cdot I(ERI_{it} < \gamma_1) + \alpha_2 ERI_{it} \cdot I(ERI_{it} \geq \gamma_1) + \beta_i IF_{it} + \theta_i + \varepsilon_{it} \quad (5)$$

Where γ_1 is a threshold value, and $I(\cdot)$ is an indication function, which is used to segment the sample according to the threshold value. The value is 1 when the corresponding condition is met and 0 if it is not. θ_i is the national individual effect. Other variables are the same as above. From the perspective of econometrics, there may be multiple thresholds, which can be extended from model (5) to double-threshold model (6), and multi-threshold model can be extended in a similar way.

$$\begin{aligned} STFP_{it} &= \alpha_1 ERI_{it} \cdot I(ERI_{it} \leq \gamma_1) + \alpha_2 ERI_{it} \cdot I(\gamma_1 < ERI_{it} \leq \gamma_2) \\ &+ \alpha_3 ERI_{it} \cdot I(ERI_{it} > \gamma_2) + \beta_i IF_{it} + \theta_i + \varepsilon_{it} \end{aligned} \quad (6)$$

For the estimation of model (5) and model (6), a panel fixed effect model is used. The average value is used to eliminate the individual fixed effect θ_i, and the residual square sum $S_1(\gamma)$ can be obtained. Then, the threshold estimated value is obtained by minimizing the residual square sum, that is $\hat{\gamma} = \arg\min S_1$. This paper applies the grid search method to solve the minimum of the sum of squared residuals. After the threshold is determined, the parameters α_i and β_i can be obtained.

In order to test the significance of the "threshold effect", we set the null hypothesis that there is no threshold (that is $H_0: \alpha_1 = \alpha_2$), Let S_0 be the sum of the squared residuals under the condition of H_0, construct a statistic $F = [S_0 - S_1(\gamma)] / \hat{\sigma}^2$ to conduct the likelihood ratio test. Since threshold γ is not identified, *F*'s asymptotic distribution is non-standard, so its threshold cannot be obtained by referring to the threshold of the standard distribution. Hansen (1996) proposes to use bootstrap to simulate the asymptotic distribution of *F* statistics, and the P value constructed based on this method was asymptotically effective. For the P value in the likelihood ratio test, if the P value is significant at the significance level of 5%, it indicates that there is at least one threshold. If the p-value is significant in the single threshold panel model, that is, *F1* is rejected, then the *F2* statistic should be used to judge whether there are two thresholds. If *F2* is rejected, it indicates that there are at least two or more thresholds. Repeat the above steps for multiple threshold tests.

In this paper, threshold effect test and threshold estimation are performed with Stata15. As shown in Table 4, the single-threshold test and double-threshold test of ERI in transport are both significant at the level of 5%, but the triple-threshold effect test is not significant. Hence, double-threshold model (6) is suitable for empirical research.

Table 4 Threshold effect tests and threshold estimation results

	F value	P value	Critical value		
			10%	5%	1%
Single-threshold	30.98**	0.030	22.722	27.621	33.709
Double-threshold	25.72**	0.047	18.985	25.320	78.628
Triple−threshold	8.48	0.597	42.310	54.969	88.993
	estimated value		**Confidence interval**		
Threshold 1	1.036		1.029		1.120
Threshold 2	0.247		0.243		0.260

Note: ** indicates the significance level at 5%; the estimation results are obtained after 500 times bootstrapping.

In addition to the threshold effect test, it is also necessary to test the threshold estimator of the double-threshold model (6). At a significance level of 5%, the critical value of the LR is 7.35. The relationship between the likelihood ratio and threshold parameters is shown in Figure 2. The dashed line in the figure is the critical value of the likelihood ratio statistic. When the threshold parameters are 0.247 and 1.036 respectively, the likelihood ratio statistic is 0, and there are two intervals smaller than the critical values near the thresholds, and these intervals are within the original acceptance range. Therefore, it can be considered that both the threshold 1 and the threshold 2 are equal to the actual thresholds.

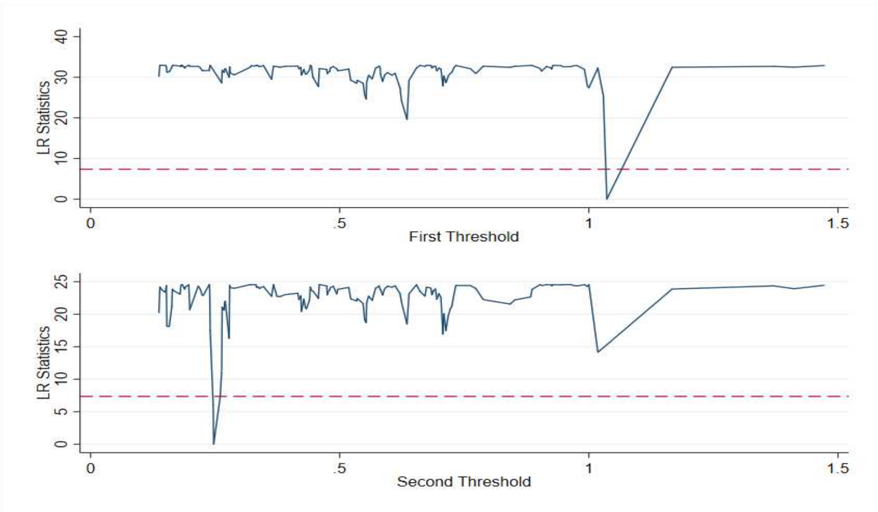

Figure 2. Estimates for thresholds 1 and 2 and 95% confidence intervals

As shown in Table 5, there is a threshold between ERI and the growth of STFP. It has a significant positive impact on the growth of STFP of the country when the ERI is lower than threshold 1,, with an effect coefficient of 0.568. This validates the Porter Hypothesis. However, when the ERI exceeds the threshold 1, it turns to be adverse effect on the growth of STFP of the countries, with an effect coefficient of 0.192. When the ERI exceeds threshold 2, the effect of environmental regulation intensity is not significant. Considering that the number of samples above threshold 2 is too small (only 9 samples), the estimation results are not reliable. Thus this part will not to be discussed. Below threshold 2, the relationship between environmental regulation intensity and the growth of STFP is an inverted U-shaped curve. That is, moderate ERI can promote the growth of STFP by forcing energy conservation and emission reduction in transport, while too high environmental regulation intensity will inhibit the growth of STFP. This result is like Wang et al. (2019), that is, in either industry or transport, excessive ERI is not conducive to the improvement of productivity.

Table 5 The estimation results of the double-threshold model

Variables	**Coefficients**	**T value**
Governance	0.115	2.67***
Diesel	0.042	1.89*
ERI (ERI<0.247)	0.568	2.94***
ERI(0.247<ERI<1.036)	-0.192	-2.02**
ERI (ERI>1.036)	0.031	0.35
Controlled variables	Yes	Yes
F	15.49***	
N	182	

Note: ** and *** represent significance levels of 5% and 1% respectively.

In addition to appropriate environmental regulation intensity, improving governance performance is an important way to promote the growth of STFP, with an effect coefficient of 0.115. Increasing the diesel price can also promote the growth of STFP to a certain extent. This is in line with our expectations. As we know, road transport is the main source of greenhouse gas emissions and casualties in transport. The increase of diesel price will restrain the consumption of fossil fuels to some extent, so as to restrain the growth of road freight volume and promote the transformation of road transport to environmentally friendly transport. Other factors are treated as control variables, and their regression results are not listed.

We use threshold 1 and threshold 2 to divide the interval of environment-related tax revenue intensity of transport, which are divided into low intensity (ERI <0.247), medium intensity (0.247 <ERI <1.036), and high intensity (ERI> 1.036). Table 6 shows the distribution of ERI interval in various countries. The ERI in 19 countries such as Australia has been at a medium-intensity level for a long time, 4 countries such as Canada have been at a low-intensity level for a long time, while Denmark is the only country that has been in a high-intensity level for a long time. In particular, the ERI in Spain dropped from medium-intensity range to low-intensity range in 2015, while the ERI in Netherland dropped from high-intensity range to medium-intensity range in 2012. Combined with the above threshold effect regression results, we can conclude that the current environmental tax intensity of transport in most OECD countries is too high, which is not conducive to the growth of STFP in transport.

Table 6 National interval distribution of environmental regulation intensity in transport

Low intensity countries	Medium intensity countries	High intensity countries
Canada, Luxembourg, Poland, Spain (15-16) Slovak Republic.	Australia, Austria, Belgium, Czech Republic, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Portugal, Sweden, Switzerland, United Kingdom, China, United States, Spain(10-14), Netherlands(12-16).	Denmark, Netherland (10-11).

Note: The year is abbreviated in brackets. For example, (15-16) means 2015-2016.

Countries such as the United States, Japan, and China have attempted to levy carbon taxes, increase fuel consumption taxes to reduce carbon emissions from transport and have achieved certain reductions. However, combined with the analysis above, the emission reductions by those methods are based on a certain degree of damage to transport economy, which are not conducive to the growth of STFP. With the development of e-commerce and trade globalization, the demand for transportation will increase further, and the emission reduction effect of environment-related taxes may not be sustainable for a long time. Clean energy technology and energy substitution can theoretically alleviate the environmental impacts caused by fossil fuels, such as electric or hybrid new energy. However, there are still some limitations in the application of clean energy vehicles at present：Such as inadequate charging facilities for long-distance transport, the demand for power in large freight cannot be met. Furthermore, the pollution problem of waste batteries has not been found a proper solution, which may lead to secondary pollution. Coupled with the relatively high prices, electric vehicles lack market competitiveness after the government cancelled subsidies. Therefore, the average annual mileage of current electric vehicles is much lower than that of gasoline-powered vehicles, and the environmental benefits brought by electric vehicles are also smaller than previously predicted (Davis, 2019). Hopefully with the increase of battery storage time, the reduction of battery composition cost and the increase of diesel price, the market share of electric vehicles is expected to increase (Danielis *et al.*, 2018). In that case, the emission reduction effect of new energy vehicles will be more significant.

In summary, on the one hand, countries should increase the research and development (R&D) of clean energy technologies for transport to promote the growth of STFP in transport. On the other hand, since road transport is the main source of environmental pollution and road casualties, the promotion and application of environmentally friendly transport should be increased, such as piggyback and pipeline transport. It can help reduce the proportion of road transport in transport structure. This can not only effectively alleviate the environmental problems of transport to a certain extent, but also reduce the occurrence of traffic accidents, thereby achieving the goal of sustainable transport.

5. Conclusions

From the perspective of sustainable development of transport, this paper proposes a new productivity index, STFP, which considers a wider range of factors, including economic growth, environmental impact and safety issues. We use the Malmquist-Luenberger productivity index based on the DEA model to measure the growth rate of STFP. We apply this model to transport sectors of 25 OECD countries and China, with greenhouse gas emissions and road casualties as undesired outputs. As a benchmark, we also consider GTFP, and perform a comparison of ranking differences. This paper also analyses the socio-economic factors that may affect the growth of STFP and GTFP. It is found that joint assessments of environmental impacts and safety issues can lead to different results. Urbanization has a significant positive impact on the growth of GTFP, while a significant negative impact on the growth of STFP. Overall, the average of STFP index is much lower than the average of GTFP index. If safety indicators are not taken into consideration, the growth rate of TFP in transport is likely to be overestimated. Further analysis found that there is a threshold effect on the impact of environmental regulation intensity on the growth of STFP. Specifically, when the environmental regulatory intensity is less than 0.247, it has a positive impact on the growth of STFP, but it turns to be negative impact after exceeding this threshold. In addition, improving governance performance and increasing diesel retail prices benefit the growth of STFP.

The STFP index proposed in this paper provides a different perspective different from that of GTFP and TFP. It considers the trade-off between survival and development in a more comprehensive scope, and can provide a new perspective for government's macro-control. First, the joint-measured productivity index can help policy makers to set sustainable development goals with reference to the better performing countries. Second, STFP that takes environmental and safety concerns into consideration can guide the allocation of efforts among government management. Countries with low STFP index rankings and high GTFP index rankings, such as China, should allocate more efforts to safety management. Furthermore, the threshold effect of environmental regulation intensity gives some inspirations. Countries with high environmental supervision should consider reducing environmental taxes and relying more on market mechanisms with greater flexibility, such as ETS, to pursue energy conservation and emissions reduction, to realize the Porter Hypothesis effect of transportation.

There are some limitations in the current research that deserve further discussion. First, there are other factors involved in the socially sustainable indicators of transport, such as noise pollution and accessibility. However, they were not included in the measurement model due to the lack of long-term statistics. Moreover, the current analysis mainly focuses on OECD countries. According to the World Bank, these countries are all developed countries. Although one developing country, China, is included in the analysis, it is not enough to explain the STFP index gap between developed and developing countries. We hope to obtain more statistics to expand this analysis to more countries and analyse income heterogeneity. Finally, different types of environmental regulations may affect the growth of STFP in different ways. This paper only analyses the impact of the overall environmental-related tax revenue intensity of transport, but does not distinguish the impact of different environmental taxes. However, it provides a steppingstone for more micro-level analysis of policy effects.

Declaration

Ethical approval: The submitted manuscript is original and not has been published elsewhere in any form or language.

Consent to participate: It is confirmed that this manuscript has been participated by all co-authors.

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