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Fuel efficiency and emission in China's road transport sector: Induced effect and rebound effect

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ABSTRACT

The main objective of this paper is to analysis how endogenous road capacity, in term of an increase in road accessibility and traffic demand ("induced effect"), exogenous efficiency policies and technological progress, in term of an increase in fuel efficiency ("rebound effect"), affect fuel consumption and thereby exhaust emission finally, the empirical estimate a simultaneous equations system of the road traffic demand, fuel consumption, exhaust emission, using the annual data of 1985–2013, we discuss the transmission mechanism of effects caused by road capacity and fuel efficiency policies, and we estimate the induced effect and rebound effect further than the previous studies, and found that the rebound effect and induced effect in China are larger than most studies of the U.S. We also prove the effectiveness of fuel efficiency policies to improve fuel efficiency, however, little help to reduce vehicle emission. In view of the pricing policy, we found that high price of new vehicle cannot inhibit Chinese demand for cars currently, what's more, rising fuel price did not encourage people to purchase energy-saving vehicles in China.

1. Introduction

Urbanization is the focus of China's economic and social development during "the 13th five-year plan" and under the new economic policies, and is also the grand strategy and the long-term driving force for expanding domestic demand. Promote new urbanization is the main way to improve China's sustainable economic development recently, urbanization is associated with large scale movements of the labor force from the country side into urban areas the result of which is to increase population density in the urban areas. The relationship between urbanization and fuel consumption has been studied by a number of authors (Sadorsky, 2013; Karathodorou et al., 2010; Kim and Brownstone, 2013; Liddle, 2004; York, 2007), Sadorsky (2013) indicated that the impact of urbanization on energy intensity is mixed, while Karathodorou et al. (2010) found that urban density affect fuel consumption through variations in the vehicle stock and in the distances traveled mostly, rather than through fuel efficiency. Kim and Brownstone (2013) found that residential density has a statistically significant but economically modest influence on vehicle usage, lower neighborhood residential density induces consumer choices toward less fuel-efficient vehicles. Liddle (2004) found that urbanization and population density have a negative impact on per capita road transportation energy use. York (2007) estimates the urbanization elasticities of fuel consumption vary between 0.29 and 0.56 in the European Union. In the process of promoting urban development, the increase in population density puts stress on the local environment (Sadorsky, 2013), the potential of traffic demand will materialise and fossil fuels' consumption will continually aggravate the urban air pollution, which brings severe challenges to sustainable economic development of China.

The conflict between reliance of economic development on road traffic and the increasingly severe pollution caused by exhausts of road traffic, is the main obstacle to sustainable development of road traffic in China. According to the National Bureau of Statistics of China, the consumption of oil in the transport sector accounts for 50% of the country's total oil consumption and road traffic is the most rapidly growing transportation mode. Beijing Environmental Protection Bureau proved that motor vehicle exhaust emissions account for 31% of the local PM2.5 sources in Beijing and are the largest source of pollution. Data of the traffic management bureau of the public security ministry show that the average annual growth rate of vehicle ownership has been 17.7% since 2001. Road transport system is becoming one of the largest and most rapidly growing oil consumers in China (He et al., 2005), resulted in serious air pollution and residents' health (Yang and

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He, 2016) which has become a major problem to realize China's new urbanization path and sustainable economic development. How can we effectively control air pollution caused by road traffic without affecting economic growth?

Economic development of China depends on unceasing increase in total transportation, but by increasing the road mileage meanwhile improving the transportation fuel economy and efficiency, can China's road traffic achieve low-vehicle carbon green development? More specifically, economic development will increase along with the road mileage (Yang and He, 2016; Kayser, 2000; Burke and Nishitateno, 2013; Huo et al., 2012; Ma et al., 2015), or road infrastructure precisely, when the supply of road infrastructure increases and road capacity is improved, it will attract new road traffic demand (Asensio et al., 2014; Gallego et al., 2013), and further generate new consumption of fossil fuels and exhaust emissions, which can be called as induced effect, generated by road traffic infrastructure. In order to control the air pollution, the policymaker formulate the corresponding policy to deal with, in Beijing where the haze problem is the most prominent has unveiled policies such as "The Regulations for the Control of Air Pollution of Beijing", "Beijing 2013–2017 Clean Air Action Plan", with main measures striving to develop public transport, conducting strict regulation of the total motor vehicles, pushing the vehicle structural optimization and adjustment, accelerating the elimination and updating of old vehicles, improving public management policies and automobile odd-and-even license plate rule and other emergency measures are taken in severe haze periods to respond to this issue. By adjusting the structure of travel modal, these traffic energy polices have reduced the proportion of high energy consumption travel modal and increased the environment-friendly travel modal, which improved the fuel efficiency of road traffic department and reduced unit mileage costs, as well as the role of technical progress of road traffic. However, the improvement of fuel efficiency have also increased vehicle usage, and thus have further generated new fossil fuel consumption and exhaust emissions, which can be called as the rebound effect (Clerides and Zachariadis, 2008), generated by the road traffic energy policies and technical progress of road traffic.

Here we measure the induced effect generated by road traffic infrastructure, the reduced generated by the traffic energy polices and technical progress of road traffic to discuss the contradiction between air pollution control and economic growth in road traffic department, and explore the effect of the traffic energy policies in China. This paper not only include the traffic demand, but also the further generated new fossil fuel consumption and exhaust emissions. The systematic structure model analysis method has been applied to test the relationships between the equation of road traffic demand, fuel efficiency, fuel consumption and exhaust emissions empirically, and the three-stage least squares method is used to estimate the model. The findings of this study will provide empirical evidence of theoretical basis of influencing mechanism in road traffic system of China, and explaining the effectiveness of the road traffic policies. Additionally, applying the elastic theory analysis method helps to insight to the influence path of road traffic infrastructure and fuel efficiency policies, by the measurement of induced effect and rebound effect. From the perspective of policy makers, the findings of this study offer the road traffic industry or relevant managers and policy makers with reasonable approach to formulate the road traffic development programmes and exhaust emission reduce policies.

2. Literature review

A large majority of studies have discussed the question of relationship between traffic demand, fuel consumption and emission all over the world. We summarized the some recently researches, as shown in Table 1, we presents the factors has been included in the previous studies, and also the areas and model.

Some authors study on the fuel consumption in real situation, take the vehicle type or road condition or driving style into consideration, discuss the impact to fuel consumption and exhaust emission, such as Yang and He (2016) estimate the elasticities of pollution emission and fuel demand with different vehicle types in road transport sector in China, Huo et al. (2012) estimated the real world fuel consumption rates of vehicles in China sold in 2009. Ma et al. (2015) discuss the fuel consumption of city buses on different road conditions and vehicle masses by different driving styles, and Hu et al. (2012) measured the fuel efficiency and exhaust emission of 16 diesel taxies on different roads in real world, discuss the relationship between the fuel efficiency, exhaust emission and road condition. What's more, the fuel price have influence on the choice of vehicle. Kayser (2000) estimate the price and income elasticities of gasoline demand, and assume that gasoline price has the influence to vehicle choice, and Burke and Nishitateno (2013) analysis the gasoline consumption and fuel economy in 43countries, and found the effect of gasoline price to the choice of fuel-efficient vehicle. Based on their researches about users behavior and factors affect a vehicle real fuel consumption and emission, we can understand the fuel consumption and exhaust emission better behind the data change, which

Table 1
List of available researches on traffic demand and fuel consumption.

Index study	Traffic demand	Fuel consumption	Fuel intensity	Emmision	Policies	Fuel price	Economic	Other factor	Country
Samimi (1995)		√					√		Australia
He et al. (2005)		√	√	√	√				China
Haldenbilen (2006)	√	√				√	√		Turkey
Brannlund et al. (2007)		√	√	√	√	√			Sweden
Paravantis and Georgakellos (2007)	√	√		√			√		Greece
Clerides and Zachariadis (2008)			√	√	√	√	√		18 countries
Karathodorou et al. (2010)	√	√	√			√	√	Urban density	42 countries
Wang et al. (2012)		√	√			√			China
Sene (2012)	√					√	√		Senegal
Hu et al. (2012)		√	√	√				Road condition	Macao
Huo et al. (2012)		√	√		√				China
Alam et al. (2013)	√	√	√		√	√	√		Bangladesh
Gallego et al. (2013)	√			√	√	√	√		Mexico, Santiago
Kim and Brownstone (2013)	√	√					√	Land use density	U.S.
Burke and Nishitateno (2013)		√	√			√	√		
Asensio et al. (2014)		√			√	√			Spain
Hymel and Small (2015)	√	√	√		√	√			U.S.
Grote et al. (2016)	√			√	√			Congestion	
Sierra (2016)	√	√	√	√					Ecuador
Stapleton et al. (2016)	√		√			√			Great Britain
Yang and He (2016)		√	√	√		√			China

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help us make an further suppose, that the effect to the vehicle choice need at least one year to generate in real world.

Instead of discuss the fuel consumption of a vehicle, more researches are interested in road transport sector total fuel consumption all over the world, Ewing and Cervero (2010) carried out meta-analysis to summarize empirical results on associations between the built environment and travel, and find that vehicle miles traveled (VMT) is most strongly related to measures of accessibility to destinations and secondarily to street network design variables. The relationship between accessibility to destinations and VMT can be measured as induced effect, Noland and Lem (2002) summarized the previous studies and confirmed that the enhancement of the road capacity of United States and Britain induced an impact on traffic demand, and held that the discovery of induced effects was conducive to facilitate the exit of relevant traffic policies.

As the reduction of fuel consumption and emission of road sector become an international problem, some researchers want to figure out how the focus on the transport policy, Asensio et al. (2014) discuss the effect of three kind of policies, speed limit in highways, commuting and regional train fares decrease and increase in the biofuel content of fuels, to the gasoline consumption in 46 provinces. Clerides and Zachariadis (2008) founds that standards have induced considerable fuel savings throughout the world. Alam et al. (2013) found the transport policy has significant implication on national energy demand scenario and economy. He et al. (2005) emphasized the importance of efficiency policies in China.

The efficient use of energy is generally justified with pricing policy and technological improvements (Haldenbilen, 2006), and many researchers also studies the rebound effect when fuel efficiency improved, the travel demand increased, Small and Dender (2007a) used a three-equation structural model to analyze vehicle kilometers of various states in U.S. in 1996–2001, the number of vehicles and fuel efficiency and estimated the rebound effect. The study found that when the income level rose or when fuel prices fell, the rebound effect was reduced. David (2012) made use of the US national data for 1996–2007 and drew similar conclusion to Small and Dender (2007a), Kent et al. (2010) extended Small and Van Dender's model, and took into account the impact of congestion on traffic demand. Brannlund et al. (2007) estimated the rebound effect of fuel efficiency on household consumption and emission, and indicated that an increase in energy efficiency of 20% will increase emissions of CO_2 by approximately 5%.

In order to analysis the relationship between traffic demand, fuel efficiency and emission, and the effect of policies, we build a road traffic system in this paper, although we mostly adopt the methodologies that were used in Small and Dender (2007a), our study is more extensive in two aspects. Firstly, we add the equation of exhaust emission, which has cause a serious air pollution in China in recent years, take the further consideration of exhaust emission also integrate the road traffic system. Secondly, we not only estimate the rebound effect, but also the induced effect generated by road accessibility, and in the previous paper, they only discuss the effect on traffic demand, we further estimate effect on the thereby fuel consumption and emission. We believe that this paper goes beyond previous studies and significantly adds to the literature in some ways.

3. Material and methods

The modeling in this paper consists of two parts, the first part is construction of the base models, by setting the corresponding assumptions to correlate the influence relationship between variables and establish the elasticity measurement and calculation models of the induced effects and rebound effects; the second part is construction of the economy model, that is, take into account the practical factors that exist in reality, to amend the base models.

3.1. Base model

By constructing a simultaneous equations system of the road traffic turnover, the number of vehicles, fuel efficiency and exhaust emissions, we motivate our empirical specification and formalize the relationship among them. We use these relationships to analysis the induced effect and rebound effect and the price elasticity.

In the specification of the road traffic system, we apply the model by Small and Dender (2007a) for a extension. Firstly, the road traffic turnover includes not only the number of transportation objects, but also the transportation distance, which reflect the outcome of road traffic comprehensively, we assume that the road traffic turnover is mainly affected by the number of vehicles, unit mileage driving costs and the attainable road mileage. Secondly, the number of vehicles refers to the number vehicles owned in a region, and it generally refers to locally registered vehicles, and that in recent years, vehicle ownership in China is growing exponentially. We assume that the number of vehicles is affected by the income level, new vehicle prices, unit mileage driving cost and other factors. Thirdly, fuel efficiency refers to the ratio of distance traveled per unit of fuel consumed, the higher the vehicle fuel efficiency is, the lower the vehicle fuel consumption per kilometer will be. In addition, fuel efficiency calculated as road transportation turnover divide by road traffic fuel consumption C, and indicated as $E = M/C$. We assume that fuel efficiency is a function of road traffic turnover, fuel prices, fuel management policy and other factors; motor vehicle exhaust contains large amounts of harmful substances, including vehicle carbon monoxide, nitrogen oxides, vehicle hydrocarbons and solid suspended solid particles, etc. Finally, we assume that the turnover of exhaust emissions is mainly affected by road traffic turnover, fuel efficiency and fuel management policy and other exogenous factors. In addition, to simplify the consideration, we assume that the driving cost per kilometer is equivalent to the ratio of fuel price to fuel efficiency. The base models in simultaneous equations system are as follows:

$$\begin{aligned}M &= M(V, P_M, K, X_M)\\ V &= V(M, P_V, P_M, X_V)\\ E &= E(M, P_F, R_E, X_E)\\ VE &= VE(M, E, R_E, X_{VE})\end{aligned} \quad (1)$$

In the above formula, M represents the road traffic turnover, V represents the vehicle population per capita, E represents the average fuel efficiency of vehicles, VE represents road traffic exhaust emission turnover; P_V represents the new vehicle price index; P_F represents the fuel price; $P_M = P_F/E$ and it represents the per-mile fuel cost; R_E represents road traffic fuel management policies and regulations; K represents road mileage, X_M, X_E, X_V and X_{VE} represent other exogenous factors.

This model is the extension of that by Small and Dender (2007a), increases the consideration of the exhaust emission model. In their model, the exhaust emission has not been taken into further consideration. Here we add the exhaust emission which is polluted by the consumption of gasoline, and constructing a more complete simultaneous equations system of gasoline consumption, the relationship between them can be estimate in our model.

Here we take two steps to solve the above equations following Small and Dender (2007a), firstly, we eliminating all endogenous variables except for fuel efficiency E, in order to explore the rebound effect which caused by the change of fuel efficiency. And secondly, we eliminating the fuel efficiency E finally. We first substitute the structural equation for both V and VE into that for M, and produce the equation in which traffic turnover is a function of P_M and endogenous variables, expressed as $\hat{M}$, and other exogenous variables denoted as Z. The equation of $\hat{M}$ as follows:

$$M = M[V(M, P_V, P_M, X_V), P_M, K, X_M] \equiv \hat{M}(P_M, P_V, K, X_M) = \hat{M}(P_M, Z_1) \quad (2)$$

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As a byproduct, the equations of vehicle population V and exhaust emission VE for the endogenous variables as follow:

$$V = V\left[\hat{M}(P_M, Z), P_V, P_M, X_V\right] = \hat{V}(P_M, Z) \tag{3}$$

$$VE = VE\left[\hat{M}(P_M, Z), E, R_E, X_{VE}\right] = \hat{VE}(P_M, Z) \tag{4}$$

After some regulatory change, the fuel efficiency improved, and the per-mile fuel cost P_M decreased, which can increased road traffic turnover M. To solve the equation above and we can get the result for the elasticity of $\hat{M}$ with respect of P_M as the rebound effect, which measuring a reduced from relating road traffic turnover M to the per-mile fuel cost P_M, the result is:

$$\varepsilon_{\hat{M},P_M} \equiv \frac{P_M}{M} \cdot \frac{\partial \hat{M}}{\partial P_M} = \frac{\varepsilon_{M,PM} + \varepsilon_{M,V}\varepsilon_{V,PM}}{1 - \varepsilon_{M,V}\varepsilon_{V,M}} \tag{5}$$

According to the above equations, the rebound effect can be divided into two parts, one part is the direct impact of the per-mile fuel cost on the road traffic turnover, which is denoted as the $\varepsilon_{M,PM}$, when the per-mile fuel cost is reduced, it would induce road traffic demand, thus increasing road traffic energy consumption and pollutant emissions. The second part is the indirect impact of fuel cost on traffic turnover via the number of vehicles, denoted as $\varepsilon_{M,V}\varepsilon_{V,PM}$, the per-mile fuel cost has an impact on the decision of purchase vehicles (Sadorsky, 2013), and the road traffic turnover further.

Since the road traffic fuel consumption is C = M/E, elasticity of the unit mileage fuel cost to road traffic fuel consumption can be expressed as:

$$\varepsilon_{C,PM} = \varepsilon_{\hat{M},PM} - \varepsilon_{E,PM} = \varepsilon_{\hat{M},PM} - \varepsilon_{E,M}\varepsilon_{\hat{M},PM} \tag{6}$$

$$\varepsilon_{VE,PM} = \varepsilon_{VE,M} \cdot \varepsilon_{\hat{M},PM} \tag{7}$$

The elasticity of the per-mile fuel cost to road traffic pollutant emissions can be expressed as:

$$\varepsilon_{VE,E} = -\varepsilon_{VE,M} \cdot \varepsilon_{\hat{M},PM} \tag{8}$$

The induced effect can be measured as the elasticity of road traffic turnover M with respect to the road mileage K, when the road-miles increase, more precisely, the accessibility of destinations increase and people can approaching further or more destination, induced the road traffic turnover, and also the consumption of energy and emission further, and this paper uses the total road-miles to define the road accessibility, yields:

$$\varepsilon_{\hat{M},K} \equiv \frac{K}{M} \cdot \frac{\partial \hat{M}}{\partial K} = \frac{\varepsilon_{M,K}}{1 - \varepsilon_{M,V}\varepsilon_{V,M}} \tag{9}$$

$$\varepsilon_{C,K} = \varepsilon_{\hat{M},K}(1 - \varepsilon_{E,M}) = \frac{\varepsilon_{M,K} \cdot (1 - \varepsilon_{E,M})}{1 - \varepsilon_{M,V}\varepsilon_{V,M}} \tag{10}$$

$$\varepsilon_{VE,K} = \varepsilon_{VE,M} \cdot \varepsilon_{\hat{M},K} = \frac{\varepsilon_{VE,M} \cdot \varepsilon_{M,K}}{1 - \varepsilon_{M,V}\varepsilon_{V,M}} \tag{11}$$

In addition, we also report for the elasticities of fuel efficiency, road traffic turnover and fuel consumption with respect to fuel price, to do so, we need substitute Eq. (2) into the formula of fuel efficiency E in Eq. (1), to eliminate other endogenous variables, which can be expressed as being affected by P_F and other exogenous variables Z, and denote as E', it is:

$$E = E'\left[\hat{M}(P_M, P_V, K, X_M), P_F, R_E, X_E\right] = E'(P_F, Z_2) \tag{12}$$

As $P_M = \frac{P_F}{E}$, substitute it in Eq. (2), to eliminate other endogenous variables, and express the turnover as being affected only by P_F and other exogenous variables Z, denoted and shown as follows:

$$\begin{aligned} M &= \hat{M}(P_M, P_V, K, X_V, X_M, X_C) = \hat{M}\left(\frac{P_F}{E'(P_F, Z_2)}, P_V, K, X_V, X_M, X_C\right) \\ &= M'(P_F, Z_3) \end{aligned} \tag{13}$$

Fuel consumption can be defined as $C' = \frac{M'}{E'}$, and the elasticities of fuel efficiency, the road traffic turnover and fuel consumption to fuel price can be expressed as:

$$\varepsilon_{E',P_F} = \frac{\varepsilon_{E,PF} + \varepsilon_{E,M}\varepsilon_{\hat{M},PM}}{1 + \varepsilon_{E,M}\varepsilon_{\hat{M},PM}} \tag{14}$$

$$\varepsilon_{M',P_F} = \varepsilon_{\hat{M},P_M} \cdot \left(1 - \varepsilon_{E',P_F}\right) \tag{15}$$

$$\varepsilon_{C',P_F} = \varepsilon_{M',P_F} - \varepsilon_{E',P_F} \tag{16}$$

3.2. Economy model

As the existence of habits, behavioral inertia, transition costs, etc., the traffic turnover, vehicle numbers, and the fuel intensity can be affected not only by current independent variables but also the lagged adjustment process, here we extend the basic model by include the lagged effect and autoregressive errors in the simultaneous equations system in order to generalize the system to account for dynamics, what's more, we assume that the error terms are first order serial correlation in the economy model, which means that the effect of unobserved factors will be similar from one year to the next, and we work with the fuel intensity I instead of fuel efficiency E in the economy model, and I defined as the reciprocal of fuel efficiency E, $I = 1/\mathrm{E}$, and there is $P_M = P_F * I$. We appoint the equation as linear in parameters with most variables in logarithms. The economy model is shown as:

$$\begin{aligned} M_t &= \alpha^m M_{t-1} + \alpha^{mv} V_t + \beta_1^m P_{mt} + \beta_2^m K_t + \beta_3^m X_t^m + u_t^m \\ V_t &= \alpha^v V_{t-1} + \alpha^{vm} M_t + \beta_1^v P_{Vt} + \beta_2^v P_{Mt} + \beta_3^v X_t^v + u_t^v \\ I_t &= \alpha^i I_{t-1} + \alpha^{im} M_t + \beta_1^i P_{Ft} + \beta_2^i R_t + \beta_3^i X_t^f + u_t^i \\ VE_t &= \alpha^{ve} VE_{t-1} + \alpha^{vem} M_t + \beta^{vem} I_t + \beta_3^c X_t^{ve} + u_t^{ve} \end{aligned} \tag{17}$$

where autoregressive errors:

$$u_t^k = \rho^k u_{t-1}^k + \varepsilon_t^k, \mathrm{k} = m, v, \mathrm{i}, ve \tag{18}$$

Here the P_M is the log fuel cost per-mile, and is equal to Pf + I, and u and ε in the above equations are error terms assumed to have zero expected value, ε is assumed as white noise sequences.

In system (13), Eq. (4) becomes:

$$\varepsilon_{\hat{M},PM}^S = \frac{\beta_1^m + \alpha^{mv} \cdot \beta_2^v}{1 - \alpha^{mv} \cdot \alpha^{vm}} \tag{19}$$

It is the measurement of short-run rebound effect, without the consideration of lagged effect. The elasticities all be instead of its coefficient in the equation, the coefficient of P_M in the equation M, β_1^m represent the elasticity $\varepsilon_{M,PM}$.

To estimate the long-run rebound effect, we need account for lagged values. The coefficients α^m, α^v, α^i, α^{ve} are indicate how much a change in one year will continue to cause changes in the next year, due perhaps

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to people's inability to make fast adjustments in lifestyle. Generally, the long-run rebound effect can be measured as:

$$\varepsilon^L_{\hat{M},PM} = \frac{\varepsilon^L{}_{M,PM} + \varepsilon^L{}_{M,V}\varepsilon_{V,PM}}{1-\varepsilon^L{}_{M,V}\varepsilon_{V,M}} = \frac{\beta_1^{\mathrm{m}}/(1-\alpha^m) + \alpha^{mv}/(1-\alpha^m)\cdot\beta_2^v/(1-\alpha^v)}{1-\alpha^{mv}/(1-\alpha^m)\cdot\alpha^{vm}/(1-\alpha^v)} = \frac{\beta_1^{\mathrm{m}} + \alpha^{mv}\cdot\dfrac{\beta_2^v}{1-\alpha^v}}{1-\alpha^{\mathrm{m}}-\alpha^{mv}\cdot\dfrac{\alpha^{\mathrm{vm}}}{1-\alpha^v}} \tag{20}$$

We apply the lagged effect to other elasticities, and solve for the long-run effect and elasticity. According to Eq. (5), and after the most variables expressed in logarithms in the system (13), to measure the rebound effect of fuel consumption, short- and long-run elasticities of fuel consumption with respect to fuel cost per-mile are:

$$\varepsilon_{C,PM} = \varepsilon_{\hat{M},PM} + \varepsilon_{I,PM} = \varepsilon_{\hat{M},PM} + \varepsilon_{I,M}\varepsilon_{\hat{M},PM} \tag{21}$$

$$\varepsilon^S_{C,PM} = \varepsilon_{\hat{M},PM}(1+\varepsilon_{I,M}) = \frac{\beta_1^{\mathrm{m}} + \alpha^{mv}\cdot\beta_2^{\mathrm{v}}}{1-\alpha^{mv}\cdot\alpha^{vm}}\left(1+\alpha^{\mathrm{im}}\right) \tag{22}$$

$$\varepsilon^L_{C,PM} = \varepsilon^L_{\hat{M},PM}\left(1+\varepsilon^L_{I,M}\right) = \frac{\beta_1^{\mathrm{m}} + \alpha^{mv}\cdot\dfrac{\beta_2^v}{1-\alpha^v}}{1-\alpha^{\mathrm{m}}-\alpha^{mv}\cdot\dfrac{\alpha^{\mathrm{vm}}}{1-\alpha^v}}\left(1+\frac{\alpha^{\mathrm{im}}}{1-\alpha^{\mathrm{i}}}\right) \tag{23}$$

The difference between the rebound effect of fuel consumption and traffic turnover can defined as weakening indicators, the impact of fuel efficiency policies, is weaken from traffic turnover to fuel consumption and exhaust emission, due to the behavior of driver chosen the efficiency vehicles. The rebound effect of exhaust emission can be measured as:

$$\varepsilon^S_{VE,PM} = \varepsilon_{VE,M}\cdot\varepsilon_{\hat{M},PM} = \alpha^{\mathrm{vem}}\frac{\beta_1^{\mathrm{m}} + \alpha^{mv}\cdot\beta_2^v}{1-\alpha^{mv}\cdot\alpha^{vm}} \tag{24}$$

$$\varepsilon^L_{VE,PM} = \varepsilon^L_{VE,M}\cdot\varepsilon^L_{\hat{M},PM} = \frac{\alpha^{\mathrm{vem}}}{1-\alpha^{ve}}\cdot\frac{\beta_1^{\mathrm{m}} + \alpha^{mv}\cdot\dfrac{\beta_2^v}{1-\alpha^v}}{1-\alpha^{\mathrm{m}}-\alpha^{mv}\cdot\dfrac{\alpha^{\mathrm{vm}}}{1-\alpha^v}} \tag{25}$$

Similarly, we measure the short- and long-run elasticity of traffic turnover, fuel consumption and exhaust emission with respect to road mileage, as the induced effect in the road traffic system. Using system (13) and Eq. (7), we can write the empirical counterparts of induced effect measurement as follows. The short- and long-run elasticity of traffic turnover with respect to road mileage can be called as induced demand effect:

$$\varepsilon^S_{\hat{M},K} = \frac{\beta_2^{\mathrm{m}}}{1-\alpha^{mv}\cdot\alpha^{vm}} \tag{26}$$

$$\varepsilon^L_{\hat{M},K} = \frac{\beta_2^{\mathrm{m}}}{1-\alpha^{\mathrm{m}}-\alpha^{mv}\cdot\dfrac{\alpha^{\mathrm{vm}}}{1-\alpha^v}} \tag{27}$$

With the respect of road mileage, the short- and long-run elasticity of fuel consumption C, may also be called induced consumption effect, measured as:

$$\varepsilon^S_{C,K} = \varepsilon_{\hat{M},K}(1+\varepsilon_{I,M}) = \frac{\beta_2^{\mathrm{m}}}{1-\alpha^{mv}\cdot\alpha^{vm}}\left(1+\alpha^{\mathrm{im}}\right) \tag{28}$$

$$\varepsilon^L_{C,K} = \varepsilon^L_{\hat{M},K}\left(1+\varepsilon^L_{I,M}\right) = \frac{\beta_2^{\mathrm{m}}}{1-\alpha^{\mathrm{m}}-\alpha^{mv}\cdot\dfrac{\alpha^{\mathrm{vm}}}{1-\alpha^v}}\left(1+\frac{\alpha^{\mathrm{im}}}{1-\alpha^{\mathrm{i}}}\right) \tag{29}$$

The short- and long-run elasticity of exhaust emission after fuel consumption, also respect to road mileage, can be called as induced emission effect, measured as:

$$\varepsilon^S_{VE,K} = \varepsilon_{VE,M}\cdot\varepsilon_{\hat{M},K} = \alpha^{\mathrm{vem}}\frac{\beta_2^{\mathrm{m}}}{1-\alpha^{mv}\cdot\alpha^{vm}} \tag{30}$$

$$\varepsilon^L_{VE,K} = \varepsilon^L_{VE,M}\cdot\varepsilon^L_{\hat{M},K} = \frac{\alpha^{\mathrm{vem}}}{1-\alpha^{ve}}\cdot\frac{\beta_2^{\mathrm{m}}}{1-\alpha^{\mathrm{m}}-\alpha^{mv}\cdot\dfrac{\alpha^{\mathrm{vm}}}{1-\alpha^v}} \tag{31}$$

Above the Eqs. (22)–(27), they are the measurement of the induced effect of traffic turnover, fuel consumption and exhaust emission with the respect of road mileage.

Using comparable estimations, we can show that the short and long-run elasticities of vehicle population with respect to new-vehicle price are:

$$\varepsilon^S_{\hat{M},PV} = \frac{\alpha^{mv}\beta_1^{\mathrm{v}}}{1-\alpha^{mv}\cdot\alpha^{vm}};\quad \varepsilon^L_{\hat{M},PV} = \frac{\alpha^{mv}\beta_1^{\mathrm{v}}}{(1-\alpha^m)(1-\alpha^v)-\alpha^{mv}\cdot\alpha^{vm}} \tag{32}$$

And, the computation of short- and long-run elasticities of fuel intensity with respect of fuel price are:

$$\varepsilon^S_{E',P_F} = \frac{-\beta_1^{\mathrm{i}}-\alpha^{im}\cdot\beta_1^m}{1-\alpha^{im}\cdot\beta_1^m};\quad \varepsilon^L_{E',P_F} = \frac{-\beta_1^{\mathrm{i}}(1-\alpha^{\mathrm{m}})-\alpha^{im}\cdot\beta_1^m}{(1-\alpha^i)(1-\alpha^m)-\alpha^{im}\cdot\beta_1^m} \tag{33}$$

$$\varepsilon^S_{M',P_F} = \varepsilon^S_{\hat{M},P_M}\cdot\left(1-\varepsilon^S_{E',P_F}\right);\varepsilon^L_{M',P_F} = \varepsilon^L_{\hat{M},P_M}\cdot\left(1-\varepsilon^L_{E',P_F}\right) \tag{34}$$

$$\varepsilon^S_{C',P_F} = \varepsilon^S_{M',P_F}-\varepsilon^S_{E',P_F};\quad \varepsilon^L_{C',P_F} = \varepsilon^L_{M',P_F}-\varepsilon^L_{E',P_F} \tag{35}$$

The Eq. (29) shows that there are two-way causation between fuel intensity I and traffic turnover M, without consideration of the indirect effect of P_F on fuel intensity via the effect of vehicle population on traffic turnover combined with the effect of traffic turnover on fuel intensity, which will be very small.

3.3. Variables and estimation method

We use the annual data from 1985 to 2013 in China. Most of the data come from National Bureau of Statistics of People's Republic of China.

3.3.1. Variables description

We describe the main variables and explore the source of the data in the Table 2, which used in our empirical analysis. Traffic turnover (M), vehicle population (V), fuel intensity (I) and exhaust emission (VE) are the independent variables in the simultaneous equations system. Road mileage (K), fuel price (PF), efficiency policy (RE), price of vehicle (PV), urbanization level (CI) and income per capita (IN) are the independent variables in the simultaneous equations system, while we consider per-mile fuel cost (PM) is derived endogenous variable. Table 3 shows the summary descriptive statistics for the variables of original data, and the variables are logarithmic and standardization in the empirical analysis.

3.3.2. Estimation of unobtainable variables

Among the above variables, we cannot get the data of C and RE from the statistical material or simple calculations. National Bureau of Statistics of People's Republic of China did not separate statistics the fuel consumption in the road traffic sector, but the fuel consumption of whole transport sector within the four modes of transport (road transport, railway

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Table 2
Data sources and interpretation of indicators.

Variables	Interpretation and source
M:	Traffic turnover, the summation of passenger traffic turnover and traffic turnover in 10:1, contains not only the number of passengers and freights but also the distance they traveled, the data are from China's National Bureau of Statistics.
V:	Vehicle population, calculate the number of registered vehicles, without the consideration of motorcycle and agrimotor, the data are from China's National Bureau of Statistics.
I:	Fuel intensity, the reciprocal of fuel efficiency, indicated as I = C/M, the ratio of gasoline consumption to traffic turnover, data are estimated on the basis of China's National Bureau of Statistics.
VE:	Exhaust emission, automobile exhaust after the consumption of fuel on the road, which contains CO, NO_X, HC, PM, etc., and we used the data of total exhaust emission of CO, NO_X, HC, PM, from Ministry of Environmental Protection China.
C:	Gasoline consumption, adjust the statistical caliber by add the gasoline consumption of uncommercial vehicle according to the report (Gallego et al., 2013), based on the China's National Bureau of Statistics.
K:	Road mileage, the total mileage of the highway; the data are from China's National Bureau of Statistics.
PF:	Fuel price, indicated with crude oil price (with the year of 2014 as the base period), and data from the database of wind.
RE:	Efficiency policy, estimate by Eqs. (30)–(32).
PM:	Per-mile fuel cost, measured as PM = PF/E, and data from database of wind and China's National Bureau of Statistics.
PV:	Price of vehicle, indicate as urban consumer price index of transportation tools, and the data are from the China's National Bureau of Statistics.
CI:	Urbanization level, the data are from the China's National Bureau of Statistics.
IN:	Income per capita, indicate as GDP per capita, and the data are from the China's National Bureau of Statistics.

transport, air transport and water transport), as the gasoline consumed mainly by vehicles, and the airplane, boat and train consume little, this paper takes the gasoline consumption of the transport sector as approximate to the road transport sector. However, the statistical data of gasoline consumption of transport sector, only calculated the gasoline consumption of commercial vehicles, which ignore the private vehicles and the vehicles for other application. Due to the deviation of statistics caliber, the statistical data of gasoline consumption of road transport sector is much smaller than the actual consumption. According to the "The Study on Different Modes of Transportation and Emission Factors and Their Comparability" (Energy Consumption, 2009), this paper using the oil apportionment method to adjust statistics caliber, and reduce the error of data, gasoline consumption of private vehicles and the vehicles for other application are taken into account, and calculation model is established as:

$$EQ = 0.95 \times (GYQ + JZQ + FWQ) + (NYQ + QTQ + SHQ) \tag{36}$$

where EQ is the uncommercial vehicles' fuel consumption, the part which not include in the statistical fuel consumption of transport sector; GYQ is the industrial gasoline consumption; JZQ is the gasoline consumption of the construction industry; FWQ is the gasoline consumption of the service industry; NYQ is the gasoline consumption of agriculture; QTQ is the gasoline consumption of other industries; and SHQ is the gasoline consumption of households.

Table 3
Summary statistics of indicators.

Variables	Mean	Std. dev	Min	Max
M	14,613	17,851	2075	56,863
V	3.9	4.2	0.6	15.9
I	4.3	1.6	1.2	6.0
VE	4860	229	4570	5143
C	36,789	18,553	12,549	80,875
K	207	124	94.3	435.6
PF	52	30	18.5	117.1
RE	1.1	0.2	1	2.1
PM	1322	496	683	2456
PV	101	1.3	98.5	102.6
CI	35.8	9.4	23.7	53.7
IN	12,061.7	12,218	860	43,320

In order to quantified the China's fuel efficiency policies, which involves a number of policies, such as Passenger Vehicle Fuel Consumption Limits, the policy of eliminating the yellow label vehicle, vehicle exhaust emission standards, oil upgrade policy, etc., and the starting and ending times varies, it is impossible to simply valued as 0 or 1, regard them as qualitative variables in the model. Therefore, this paper establishes the fuel intensity prediction model which excludes policy influential factors firstly, to estimate the fuel intensity in the absence of efficiency policies, we includes all other endogenous variables involved in the fuel intensity equation of system (17) and a single time trend, denoted as:

$$I_t = \alpha^{IR} I_{t-1} + \beta^{IR} X_t^{IR} + u_t \tag{37}$$

where I represents fuel intensity, X_t^{IR} represents all the endogenous variables except fuel efficiency policies. The coefficient α^{IR} of the lagged dependent variable can be interpreted as arising from the practical adjustment model, shown as:

$$I_t = I_{t-1} + \gamma\left(I_t^* - I_{t-1}\right) + u_t, \text{ where } \gamma = 1 - \alpha^I \text{ and } I_t^* = \frac{\beta^{IR} X^{IR}}{1 - \alpha^{IR}} \tag{38}$$

where I_t^* denotes a long-run desired value for fuel intensity, and γ represents the fraction of the fleet that turns over each year, changing portion of the stock basing decisions in year t desire to shift the vehicle stock toward one with fuel efficiency.

We assume that the efficiency policies are binding whenever the desired intensity is more than fuel intensity without policies, which is an estimate of the difference between desired value of fuel intensity and that achieved in real driving, the measurement is shown as the following formula:

$$R_E = \max\left\{\frac{I_t^*}{\bar{I}_t}, 1\right\} \tag{39}$$

3.3.3. Instrumental variables and exclusion restrictions

Taking into account the existence of heteroscedasticity and the autocorrelation and non-linear transformations of variables, this paper made use of the 3SLS estimation method to estimate the system, which is an instrumental variables estimator proposed by Zellner and Theil (1962), make use of correlations among disturbances across our four equations to obtain more efficient parameter estimates than single-equation methods such as 2SLS. The basic process of 3SLS is use 2SLS estimation model equations firstly, then use the GLS estimation model system, namely, 3SLS = 2SLS + GLS. Normally the 3SLS uses all exogenous variables of the system as instruments, in the empirical estimation, we set the instrumental variables include the sample size length is 1987–2013, the number of observed variables is 27 and the number of the total observed variables of the system is 79; use 3SLS to estimate the above model systems, and in the process of estimation, control the tool variables constant C, policies and regulations RE, total road mileage K, turnover first-order lag M (−1), the income level I, vehicles ownership first-order lag V (−1), fuel intensity first-order lag I (−1), and the parameter estimation results obtained are as follows.

4. Estimation results

We present the estimation results of the equations in the simultaneous equations system not only by the method of 3SLS, but also the

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results of OLS method as a comparison, in order to confirm that Small and Dender (2007a) indicated that the OLS method overestimates the absolute value of the structural coefficients and the rebound effect. The rebound elasticity, induced elasticity and price elasticity also measured in this section, and estimated by three different sample length, 1985–2013, 1985–2004, and 2005–2013.

4.1. Estimation results of simultaneous equations system

The result of estimating the structural system Eq. (17) are presented in Tables 4–7, including all the estimated coefficients. Each table shows the estimated results by 3SLS method and OLS method.

4.1.1. Road traffic demand equation

Table 4 shows parameter estimation results of the road traffic demand equation, which explaining traffic turnover. Except the coefficient of M (−1), all of the coefficients with a high degree of precision by the method of 3SLS, and OLS method except the coefficient of V. The adjusted R-squared indicates that the model has strong explanatory power. The coefficient results shows that the vehicle stock has a positive effect on the road traffic turnover, moreover, when road accessibility is enhanced, the road traffic turnover also increases and there is a positive influential relationship between them. Road accessibility has an attracting effect on road traffic demand, and when the unit driving mileage fuel cost has a significant negative correlation with the road traffic turnover, while the road traffic driving cost increases by 1%, the road traffic turnover decreases by 1.25%. In addition, the income elasticity is −0.55 in the short run, and −0.42 in the long run, when income increases, the road transport turnover should increase, while the coefficient on income indicates the negative relationship between them, probably because the consideration of vehicle population in the equation, the income improved encourage people purchase more vehicles, travel more, which has been explain by the coefficient of V, except of this influence path, the income improved also encouraged people will pay more attention to safety, they will travel by high-speed rail or air transport instead, which is more safety, as Atack et al. (2009) pointed out that with increased income, people tend to choose air transport. What's more, high-speed rail develops very fast in China in recent years, which generate a part of transition.

4.1.2. Vehicle stock equation

In the estimation results of vehicle stock equation, as shown in Table 5, all the coefficients have gone through the *t*-test and all have a significant influence on the vehicle stock, however, the estimation results vary from 3SLS and OLS, the OLS results are sensitive to the small changes in the specification, while the 3SLS results are quite steady. According to the results of 3SLS method, the coefficient of lagged vehicle stock V (−1) is 0.99 indicated that there is strong inertia in contracting the vehicle stock, which also reflects the transaction cost. Our measure of road traffic turnover M has a statistically significant negative effect on the number of vehicles, but the effect is small, traffic turn over improve 1%, the vehicle decrease 0.094%, perhaps indicating the situation of traffic congestion, form the results of Table 4, the car stock increase 1%, encourage the traffic turnover 1.27%, which may worsen traffic congestion, and decrease the desire to buy vehicle in return. While new vehicle prices have a positive impact on the number of vehicles, that is, when new vehicle prices increase, the desire of customers to buy vehicles won't fall, indicating that in the decision of customer to buy a vehicle, the new vehicle price does not inhibit consumer demand for purchasing and holding vehicles, the study of Knez et al. (2014) and Small and Dender (2007b) also confirm this.

Table 4
Results of road traffic demand equation.

Variable	3SLS Coefficient	3SLS Std. error	3SLS *t*-Statistic	OLS Coefficient	OLS Std. error	OLS *t*-Statistic
C	8.1562***	3.1183	2.6155	2.8556***	1.4082	2.0278
M (−1)	−0.3152	0.4117	−0.765	0.4142***	0.1831	2.2614
V	1.2713***	0.7193	1.7674	0.4613	0.3918	1.1772
PM	−1.2709***	0.3673	−3.459	−0.4468***	0.1438	−3.1052
K	1.1260***	0.4301	2.6181	0.5888***	0.2875	2.0477
IN	−0.5482***	0.2759	−1.986	−0.1714	0.1381	−1.2406
Adjusted R-squared		0.944895		0.977630		
S.E. of regression		0.098310		0.063747		
Sum squared resid		0.202960		0.089400		
Durbin-Watson stat		1.498063		1.998495		
No. observations 27						

*** Indicates the coefficient is statistically significant at the 5% level.

Table 5
Estimation results of vehicle stock equation.

Variable	3SLS Coefficient	3SLS Std. error	3SLS *t*-Statistic	OLS Coefficient	OLS Std. error	OLS *t*-Statistic
V (−1)	0.9957***	0.0186	53.321	0.9601***	0.0483	19.847
M	−0.094***	0.0252	−3.736	0.0771***	0.0427	1.8035
PV	0.0094***	0.0017	5.5145	−0.0039***	0.0021	−1.8376
PM	−0.1358***	0.022	−6.088	0.0471***	0.0233	2.0199
Adjusted R-squared		0.998717		0.998724		
S.E. of regression		0.011148		0.011117		
Sum squared resid		0.001491		0.001483		
Durbin-Watson stat		1.945248		1.805680		
No. observations 27						

*** Indicates the coefficient is statistically significant at the 5% level.

4.1.3. Fuel intensity equation

Estimation results of the fuel intensity equation are shown in Table 6, and the reciprocal of fuel intensity I, that is fuel efficiency. According to the estimation results by the method 3SLS, the significant negative effect of road traffic fuel efficiency policies can equivalently be viewed as confirmation of the effectiveness of China's road traffic fuel efficiency policy, namely, the fuel policies, reduced the intensity of fuel consumption, enhanced the fuel efficiency of vehicles. The traffic turnover also negative related to fuel intensity, which means fuel efficiency improved 0.1% along with the traffic turnover increased 1%, probably because the effect of automobile engine performance and driver behavior, such as the longer travel distances, the automobile engine performance better. However, results shows that fuel prices don't have significant impact on fuel intensity, which cannot prove the assumption that fuel price increase will altering people to purchase the efficiency new car, and indicates that the rising fuel price did not encourage people to purchase more efficiency car in China, what's more the effects of fuel prices on fuel efficiency are mainly manifested

Table 6
Results of fuel intensity equation.

Variable	3SLS Coefficient	3SLS Std. error	3SLS *t*-Statistic	OLS Coefficient	OLS Std. error	OLS *t*-Statistic
C	0.9467***	0.1079	8.7703	0.9690***	0.1168	8.2937
I (−1)	0.7070***	0.0410	17.223	0.7028***	0.0444	15.8087
M	−0.105***	0.0276	−3.819	−0.123***	0.0289	−4.2502
PF	−0.0106	0.0354	−0.2991	0.0193	0.0337	0.5745
RE	−0.3265***	0.0210	−15.5254	−0.3259***	0.0226	−14.4029
Adjusted R-squared		0.992240		0.992543		
S.E. of regression		0.020914		0.020501		
Sum squared resid		0.009623		0.009247		
Durbin-Watson stat		2.297545		2.277871		
No. observations 27						

*** Indicates the coefficient is statistically significant at the 5% level.

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Table 7
Results of vehicle emission equation.

	3SLS			OLS		
Variable	Coefficient	Std. error	*t*-Statistic	Coefficient	Std. error	*t*-Statistic
C	1.5779	1.2842	1.2287	1.5365	1.6021	0.9590
M ∗ I	0.0103[*]	0.0075	1.3617	0.0104	0.0105	0.9892
RE	0.0256[*]	0.0184	1.3861	0.0197	0.0258	0.7623
VE (−1)	0.5595[*]	0.3486	1.6049	0.5728	0.4351	1.3166
Adjusted R-squared		0.413938		0.423405		
S.E. of regression		0.023192		0.023004		
Sum squared resid		0.002151		0.002117		
Durbin-Watson stat		2.202013		2.141028		
No. observations 27						

[*] Indicates the coefficient is statistically significant at the 20% level.

in the following aspects: change in driving habits, promote technical progress and encourage people to buy energy-saving vehicles, which reflect the transaction cost of altering vehicles and need time to adjust. Due to the condition of the automobile engine performance and other factors, when traveling longer distances, the average fuel consumption decreases, that is, there is a positive correlation between the increase in the road traffic turnover and fuel efficiency.

4.1.4. Vehicle emission equation

In the estimation results of vehicle emissions equation, as shown in Table 7, the fuel consumption M ∗ I do have significant effects, as do fuel efficiency policies RE and the lagged vehicle emission VE (−1). However, the relationship between fuel efficiency policies RE and vehicle emission is positive, which means the fuel efficiency policies does not have effect on the reduction of vehicle exhaust emissions, this presumably due to the rapid expansion of traffic turnover, the road traffic fuel efficiency policies has significant influence on the improvement of fuel efficiency, but cannot inhibit the expansion of vehicle stocks and traffic turnover. M ∗ I represents the fuel consumption, and as expected, the more consumption of fuel, the more vehicle emission would generated, as fuel consumption increased 1%, the exhaust emission increased 0.01%, which can be viewed as the total emission factor of gasoline in road sector. The coefficient of lagged exhaust emission VE (−1) is 0.56, means that any short run effect on vehicle emission, for example from an improvement of automobile emission standard, will be magnified by a factor of $1/(1 - 0.56) = 2.27$ in the long run.

4.2. Measurement of elasticities

The rebound effect and induced effects are measured as the elasticity of M, C and VE with respect of PM, the induced effects are measured as the elasticity of M, C and VE with respect of K, which extend the previous studies, we divide the rebound and induced effect into three types with the further consideration of fuel consumption C and vehicle emission VE.

4.2.1. Rebound effect

The measures of rebound effect are shown in Table 8, and the estimation results in three different period samples, first the full time from 1985 to 2013, and the early period from 1985 to 2004, which lack of the data of vehicle emission, and the late period from 2005 to 2013. Compare the results in different period, we found that the rebound effect from 2005 to 2013 are large than the rebound effect from 1985 to 2004, which contains the increase of income level, the improvement of traffic structure, and so on, the rebound effect increased along with income. Restricting the sample causes the rebound effect to rise. Compare with the short run rebound effect and the long run rebound effect, the short run is quite larger, which means the driving cost is quit sensitive in China, and customers mostly react to the unit mileage fuel driving cost by changing the transport mode in the long run. The rebound effects describe the impact of driving costs on the road traffic turnover, fuel consumption and exhaust emission, which presents the effect of road traffic energy-saving policy or technology improvement, so that when the unit mileage driving fuel cost is reduced, it boosts road traffic demand, thereby increasing the road traffic energy consumption and pollutant emissions, which is contrary to objectives of the policy and technical progress goals. According to the results shown in Table 8, when the fuel efficiency policies or technical improvement, reduced the fuel costs per-mile by 1%, in the short run, it will make road traffic demand, road traffic fuel consumption and vehicle emissions increase by 1.3%, 1.2% and 0.01% respectively, while in the long run, it will increase 0.17%, 0.1% and 0.0025% respectively from 1985 to 2013.

With the comparison of other estimates of rebound effect of the U.S. transport sector, our estimate of the short run demand rebound effect is larger, the long run demand rebound effect is a little smaller. As in the results of Small and Dender (2007a), the short run rebound effect is −0.0452, and long run effect is −0.2221, in the results of Kent et al. (2010), which extend the consideration of congestion, the short run rebound effect is −0.048, and long run effect is −0.241.

4.2.2. Induced effect

The estimation of induced effect of traffic turnover M, fuel consumption C and vehicle emission VE are shown in Table 9, from three different time periods. The induced effect indicates that the road capacity improved, along with the road traffic demand boosts, and also the road traffic energy consumption and emissions increased. Compare with the study of Kent et al. (2010), which discuss the induced effect from total road mileage and urban lane width, our estimation of induced effect is larger both in the short run and long run. According to the estimation results, when the road accessibility increases by 1%, road traffic demand increases by 1.26%, road traffic fuel consumption increases by 1.12%, and exhaust emissions increase by 0.012%, and the long-term induced effects are smaller than the short-term. Compare with the induced effect in different periods, we can found that the short run induced effect is obvious in the recent period of 2005–2013, while the long run induced effect performance better in the past period of 1985–2004. What's more, in the past period, the long run induced effect is larger than short run.

4.2.3. Price elasticities

We compute the short run and long run elasticity of traffic turnover with respond to vehicle price and fuel price in three time periods, as shown in Table 10. The elasticity of traffic turnover with respond to vehicle price indicates that the increasing vehicle price reduced traffic demand in the short run a little, while did not suppress traffic demand in the long run, what's more, in the recent period of 2005–2013, not

Table 8
Measures of rebound effect.

	1985–2013		1985–2004		2005–2013	
Rebound effect	Short run	Long run	Short run	Long run	Short run	Long run
M type	−1.346	−0.1694	−0.0647	−0.3144	−1.0118	−1.3983
C type	−1.204	−0.1084	−0.0498	−0.1497	−0.4650	−0.3571
VE type	−0.012	−0.0025			−0.0054	0.0391

Table 9
Measures of induced effect.

	1985–2013		1985–2004		2005–2013	
Induced effect	Short run	Long run	Short run	Long run	Short run	Long run
M type	1.2559	1.0987	0.1769	0.3809	2.0228	0.0149
C type	1.1235	0.7032	0.1361	0.1814	0.9295	0.0038
VE type	0.0115	0.0257			0.0107	0.0016

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Table 10
Summary of price elasticity.

Price elasticity	1985–2013 Short run	1985–2013 Long run	1985–2004 Short run	1985–2004 Long run	2005–2013 Short run	2005–2013 Long run
$\varepsilon_{\hat{M},PV}$	−0.0060	0.1183	−0.0011	0.1031	0.0348	0.0985
ε_{E',P_F}	0.1441	0.4778	0.0631	0.1689	2.1016	2.0784
ε_{M,P_F}	−1.5403	−0.2504	−0.0688	−0.3676	−4.6135	−4.3985
ε_{C',P_F}	−1.3962	0.2274	−0.0057	−0.1987	−2.5119	−2.3201

only the long run, but also the short run, vehicle price cannot inhabit the traffic demand. The elasticity of traffic turnover with respond to fuel price are larger, when fuel prices rises, drivers may change their driving behavior to reduce the driving costs or alter energy-saving vehicles, which indicated in the long run elasticity. The fuel price rising 1%, the fuel efficiency improving 0.14% in short run and 0.48% in the long run from 1985 to 2013, and traffic demand decreasing, also the fuel consumption. With the compare of different time periods, we can found that the elasticities in recent period of 2005–2013 are quite larger than in the past period of 1985–2004.

5. Conclusions

This paper have shown that including a measure of vehicle emission in an aggregate traffic system, which helps clarify at least three phenomena of interest to mechanism and policy. First, we confirm the effectiveness of road transport fuel efficiency policies in China, which effect fuel efficiency significantly, while have little help to reduce vehicle emissions, as the repaid expansion of vehicle stock and traffic turnover, we suggest the policy maker focus on the traffic demand structure in the next, and intensify the market-oriented road traffic energy-saving policy, such as the adjustment of fuel cost per-mile, as we found in the empirical estimation, fuel cost per-mile decrease the traffic demand and vehicle stock, which means the fuel cost per-mile is one of the important consideration in the decision of travel or not, and the decision of purchasing energy-saving car or not. Second, we estimate the influence mechanism of road traffic system in China, from road capacity to the vehicle emission, through the traffic demand, fuel consumption, and also the other influence factors, such as fuel price, income, urbanization. Third, we discuss the induced effect and rebound effect more further than the previous studies, which contains three types, and estimated in three different time period.

Our estimates of the rebound effects and induced effects are larger than the most others, which studies the traffic sector of the U.S., and we establish a simultaneous structural model including vehicle emission equation, what's more, the different control variables may also be the source of difference. Quantitatively, we estimate the total emission factor of gasoline of road traffic sector in China, indicates that fuel consumption increased 1%, the exhaust emission increased 0.01%. We also find that rebound effect and induced effect decreased in magnitude over our sample period.

Traffic demand increased with the development of new urbanization and sustainable economic, due to the associated large scale movements of the labor force from the country side into urban areas, economic development of China depends on unceasing increase in total transportation. The methods developed here and the empirical analysis will facilitate more complete and accurate policy evaluation to deal with the conflict of economic growth supportive and environment protection in the road transport sector.

Among the fuel efficiency policies in China, oil price subsidies created significant fiscal burden besides inflating fuel demand in China (Alam et al., 2013). To achieve energy conservation and reduce emissions from road traffic the paper has that the number of vehicles and road accessibility both have a significant impact on road traffic turnover, while the driving cost has a significant negative impact on road traffic demand, and new vehicle prices have a significant negative impact on the number of vehicles. Compared with driving cost, new vehicle price is the main consideration when consumers choose to buy and hold a vehicle. Therefore, the number of vehicles can be controlled or the ownership of high energy consumption vehicles can be reduced by formulating relevant tax policy to guide new vehicle prices. Besides, policy can raise driving cost through parking fees, fuel tax and other relevant policies, to inhibit demand for vehicles with high pollution, so as to increase the proportion of public transport and environment-friendly modes of transportation. Accessibility of transportation modes with high energy consumption can be reduced by vigorously advocating and promoting public transport, for example, congestion charges and parking fees have inhibited the vehicle travel accessibility to a certain extent.

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