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Investigating the rebound effect in road transport system: Empirical evidence from China

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ABSTRACT

Improving energy efficiency is recognized as a cost-effective way to conserve energy, it is also considered as a primary instrument in many energy policies. Nevertheless, efficiency improvements could spawn unintended rebound effects, which could offset the expected energy conservation and its associated CO_2 reduction. This paper therefore intends to investigate the rebound effect in China's road transport system over the sample period 2003–2013. Utilizing a city-level dataset and a stochastic frontier rebound effect model, we found that there was considerable room to improve the fuel efficiency further in China's eight economic regions. Meanwhile, we also found the occurrence of rebound effects that the magnitudes of which ranged from ranged from 7.2% to 82.2%. The rebound magnitudes were shown to be negatively associated with the level of retail fuel prices, indicating that imposing carbon taxes might be a favorable way to downgrade the rebound effect. All these imply the necessity to design an appropriate policy that could facilitate efficiency improvements as well as attain CO_2 reduction purpose.

1. Introduction

China has experienced rapid economic development over the past decades, which led to the enormous increase in energy consumption. Since 2009, China has become the world's largest energy consumer and carbon emitter. In 2014, China's energy consumption reached 2.97 billion tons, which accounted for 23% of the global total and contributed nearly 27.5% of the world's carbon emissions (BP, 2015). Confronting the severe smog issue as well as facing the energy security challenge, to conserve energy and reduce carbon emissions has become more imperative than ever. Improving energy efficiency, out of many means, is considered as an expedient measure. In fact, China's 11th Five Year Plan (2006–2010) has placed energy efficiency improvements at the same level as other national policies. The latest 13th Five Year Plan (2016–2020) further emphasized the importance of achieving energy conservation and carbon emissions reduction targets. By 2020, the Chinese government aims to reduce energy intensity (energy consumption/GDP) and carbon intensity (CO_2/GDP) by 15% and 40–45% compared with the 2005 level.

However, the anticipated benefits of energy efficiency improvements may be undermined by rebound effect. As discussed in, e.g., Khazzoom (1980), the rebound effect is an unexpected second-order behavioral response, which occurs due to efficiency improvements induced price fall.[1] As a result, it could partially or entirely offset the expected energy savings amount.[2] The occurrence of rebound effects thus creates challenges for policymakers while designing energy efficiency policies: the prevention of rebound effects seems to favor energy conservation concept; however, too much prevention may impede energy efficiency improvements, which could further inhibit productivity and GDP growth.

This paper thus intends to investigate the rebound effect in China. The empirical analysis places China's transport sector at the core since this sector has a significant economic role in China's economic development and the energy consumption in this sector has an annual rate of

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[1] The price fall can be framed in two cases. The first case is the absolute decrease of price. This is most likely to happen in a long term and in a general equilibrium circumstance since the market clearance price needs time to be adjusted. Another case is the relative decrease of price. It means that when energy efficiency improved, less amount of energy is required to produce same level of energy service, and therefore the cost of energy for per unit energy service is relatively "cheaper". This is more likely to happen in a short run and in a partial equilibrium context (energy price is not affected by and will not affect other goods). In this paper, energy price fall is dwelled in the second case.

[2] In an extreme case the final energy consumption will even increase, i.e., the "taken-back" energy consumption exceeds the expected saving amount. (see, e.g., Sorrell, 2007). This notion is however precluded from the rebound effects analysis in this paper as there has found rarely empirical evidence of which.

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9.34% (China Statistics Press, 2013). Specifically, the study is carried out in the road transport sector that undertakes the majority of passenger and freight traffic. The definition of the rebound effect in this paper refers to the most familiar and widely studied micro-level direct rebound effect. In this case, the occurrence of rebound effect is commonly caused by the fuel efficiency improvements induced lower cost of fuel. The macro-level economy-wide rebound effect, which is often analyzed using CGE models,[3] is beyond the research scope of this study.[4]

Two things are worth to be discussed here. First, since the estimation of the rebound effect is based on energy efficiency, it is essential to define the energy efficiency properly (see, e.g., Sorrell et al., 2009). This paper thus grounded the concept of fuel efficiency in production theory. It could provide a solid base for interpretation (see, e.g., Filippini and Hunt, 2011; Bhattacharyya, 2011). In this context, the estimated fuel efficiency denotes the potential of fuel consumption reduction that could provide the same level of energy service.[5] This potential fuel consumption reduction, or the underlying fuel efficiency,[6] in line with Small and Van Dender (2007), is "*determined jointly by consumers and manufacturers accounting for the price of fuel, the regulatory environment, and their expected amount of driving.*"[7] Thus, the fuel efficiency improvements comprise endogenous technical progress and exogenous efficiency enhancement. Second, besides of measuring the magnitude of the rebound effect, we believe it is also crucial to evaluate the impacts of factors that could affect the sizes. These factors include for example retail fuel prices, the vehicle carrying capacity, GDP per capita, etc.

Hence, to estimate rebound effect and the impacts of its determinants, we adopted a stochastic frontier approach proposed by Orea et al. (2015). One advantage of using this model is that it could directly estimate the rebound effect without assuming an efficiency improvement rate. Fuel efficiency in this model denotes the distance between observed fuel consumption and optimal fuel demand. The rebound effect in this model is defined according to Saunders (2000) and Sorrell and Dimitropoulos (2007), which is the elasticity of energy demand on energy efficiency change.

Our empirical analysis is carried out for the sample period 2003–2013 using a city-level nation-wide dataset in China's road transportation system.[8] The dataset consists of passenger and freight transport divisions. Primary results show that during the sample period, the nation's average fuel efficiency increased from 0.654 to 0.775 while the average rebound effect expanded from 15.4% to 48.2%. The growth rate of rebound effect was nearly ten times faster than efficiency improvements. Further, distributions of the fuel efficiency and the rebound effect were severely unbalanced among China's eight economic regions. On average, the East Coastal Area demonstrated the highest fuel efficiency (0.914) and the largest rebound effect (82.2%), whereas the Northeast Region had the lowest fuel efficiency (0.612) and the smallest rebound effect (7.2%).

To this end, the paper contributes to this strand of literature in the following aspects: i) it adopts a novel approach that can directly measure the theoretically defined rebound effect, ii) it carries out the analysis in China's passenger and freight transport divisions that have not yet been widely investigated, and iii) it is the first study that examines the nation-wide fuel rebound effects as well as CO_2 mitigation capability in China's road transport system. The rest of the paper is organized as follows. A brief literature review is provided in Section 2. Section 3 introduces the methodology. Section 4 describes the data and elaborates the empirical specification. Results and discussion are shown in Section 5. Section 6 concludes and provides policy implications.

2. Literature review

Rebound effects studies are abundant (see, e.g., Sorrell, 2007; Freire-Gonzalez, 2011; Lin and Du, 2015; Turner and Katris, 2017; Yang and Li, 2017; Li and Jiang, 2016). Concerning the research subject of this paper, this brief literature review sheds light on studies that explored the rebound effect in the transport sector. Despite this genre of literature is plenty, a great number of them studied the personal transportation division, and the estimated magnitudes differ a lot due to differences in definitions, methods, and data used.

For developed countries, Small and Van Dender (2007) estimated direct rebound effects of the US personal transport sector for 1961–2001 using a structural model. The short- and long-term magnitudes were 4.7% and 22% respectively. Frondel et al. (2012) studied direct rebound effect in the personal transport sector in Germany. The rebound effect magnitudes were found to be 56–66% using a panel method. Hymel et al. (2010) utilized a system of equations to analyze the personal motor-vehicle travel in the US for the period 1966–2004. Results showed that the direct rebound effect was about 16%. Barla et al. (2009) utilized a panel model to calculate the rebound effect of Canadian private vehicles. The estimated short-term and long-term rebound effect magnitudes were around 8% and 20% respectively. Odeck and Johansen (2016) estimated direct magnitudes of rebound effect using the error correction model for Norwegian transport sector over the period 1980–2011. They found that short-run and long-run rebound effects were 26% and 6%.

For developing countries, Wang et al. (2012) examined direct rebound effects for passenger transport in urban China of 28 provinces between 1994 and 2009. They utilized a linear approximation of the Almost Ideal Demand System (LA-AIDS) model to carry out the empirical analysis. The magnitude was found to be 96%. Lin and Liu (2013) investigated rebound effects of passenger transportation in China between 1994 and 2010 also using a LA-AIDS model. They found the existence of backfire rebound effect and the magnitude was about 107.2%. Moreover, they discovered that the rebound effect could be diminished if the refined oil pricing mechanism is reformed. Wang and Lu (2014) estimated direct rebound effects in China's road freight transport. By using a double logarithm regression equation and error correction model, they found that the long-term magnitudes were 84%, 52%, 80% and 78% for the entire, the eastern, central, and western regions of China during the period 1999–2011. Zhang et al. (2015) evaluated direct rebound effects for road passenger transportation in China during 2003–2012 using a dynamic panel quantile regression approach. The average size of the rebound effect was found to be 25.53% and 26.56% for the short- and long-run respectively. Steren et al. (2016) attempted to evaluate the rebound effect from the perspective of subsidizing energy efficient cars in Israel's private transportation sector using a natural experiment method. They found a 40% rebound effect on the average level and suggested levying a Pigouvian tax to increase the fuel prices by 10% to help reduce the rebound effect magnitude. Zhang et al. (2017) utilized a two-stage Almost Ideal Demand System (AIDS) model and estimated the fuel-consumption related carbon emissions rebound effect at the provincial level in China's private car sector. They found the evidence of all rebound effect types (super conservation, partial and backfire), and concluded that the rebound effects among the provinces appeared a convergence trend over time. They also demonstrated that the household expenditure and population density generated negative and positive impacts on the magnitude of carbon emissions rebound effect respectively.

[3] See comprehensive review of macro-level rebound effects studies in Sorrell (2007).

[4] The research scope is limited by the adopted model, however, we believe the study and the associated discussions made scientific meaningful contribution to this school of literature.

[5] The energy service by here is referred to as driving distance.

[6] See detailed discussion and definition underlying energy inefficiency in Filippini and Hunt (2011).

[7] Small and Van Dender (2007) defined and estimated fuel efficiency using a structural model, whereas this paper formulates and calculates the fuel efficiency according to a stochastic frontier framework.

[8] Considering the space limit and to illustrate the results (fuel efficiency and rebound effects estimates) more effectively, we present and discuss the results at the provincial/regional level. The provincial/regional level results are aggregated city-level results. The detailed city-level fuel efficiency and rebound effects estimates can be acquired from the first author.