[*ACHIEVING LOW-CARBON URBAN PASSENGER TRANSPORT IN CHINA: INSIGHTS FROM HETEROGENEOUS REBOUND EFFECT*]

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Overview

The rapid increases of energy consumption and its corresponding carbon emissions in transportation sector threaten China's energy security and ecological environment. The effectiveness of energy efficiency improvement is of great importance in achieving low-carbon passenger transport in China, while it depends on the magnitude of rebound effect. The feedback mechanism of energy efficiency improvement on energy consumption is straightforward: a higher efficiency means a lower real price of energy services, and hence the original energy conservation might be partly or even totally offset because of consumers' behavior changes responding to a lower price of energy services. Furthermore, the rebound of energy consumption would also result in the rebound of CO_2 emissions due to the same reasons because most of CO2 emissions stem from fossil energy combustion. Therefore, a clear acknowledgement of rebound effect has important implication for the effects of energy saving and emission reduction by improving energy efficiency and informs policy makers more policy implications on energy and environmental issues. Particularly, regional heterogeneity in rebound effect might make the effectiveness varying in different regions. However, the heterogeneity in rebound effect and the policies to deal with it are still less studied. This paper fills the research gap by highlighting the role of heterogeneous rebound effect and carbon tax in achieving low-carbon urban passenger transport.

Methods

We assume a two-stage budgeting process to model the decisions of households on living expenditure. In the first stage, consumers would distribute their living expenditure among four categories: (i) food, (ii) transportation and tele-communication (T&Tc), (iii) residence and (iv) others. In the second stage, expenditure on these categories would be further allocated among commodities in each category. The two-stage budgeting reflects that consumers make choices in sequential steps. We adopt the AIDS model proposed by Deaton and Muellbauer (1980) to depict the living expenditure of households. Furthermore, using the above classification of categories and commodities, we extend the AIDS model into a two-stage model following Brännlund et al. (2007). In the first stage, households allocate their living expenditure among four categories. The second stage comprises the allocation of commodities within categories. The price and expenditure elasticities of demand for each category and commodity can be calculated. In the simulation, energy efficiency improvement would reduce the effective price of energy services and thus reduces energy cost per unit. Thus, we model the increased energy efficiency as a price reduction. Rebound effect comes from a reduction of the price of energy services caused by energy efficiency improvement. Contrarily, carbon tax can increase the cost of fossil energy using, and thus would reduce the magnitude of rebound effect.

Results

First, backfire effect is observed in urban passenger transport among all 30 provinces in China. That indicates energy efficiency improvement in transportation sector increases CO2 emissions, rather than reduces them. The energy efficiency improvement for urban passenger transport in China does not achieve its expected benefits for CO2 emission reduction. As a largest developing country in the world, the demand for transportation service is far from being satisfied, making urban households more sensitive to the decrease of transportation cost caused by energy efficiency improvement.

Furthermore, there is a large heterogeneity in the magnitude of the rebound effect among different provinces. Also, we found that the CO2 rebound effect shows a non-linear trend with the increasing living standards at national level. The heterogeneity among provinces and across time might be explained by the disparities in transportation consumers' response under different degree of economic development. It is highly possible that there is a threshold for passenger transport consuming. Before the threshold, private vehicles are rarely consumed by households. Rebound effect mainly occurred in public transport. The poorer a province, the more marginal consumers of public transport service. While, after the threshold, more households are able to afford private vehicles, and their responses become more elastic before saturation, making rebound effect increase with income.

Table 1. Elasticities, rebound effect and corresponding carbon tax by province

Province	Expenditure	$t\eta_{(2)11}$	$t\eta^{e}_{(2)1}$	RE	Carbon tax
	(1)	(2)	(3)	(4)	(5)
Qinghai	3214	0.2704	2.0437	131.7%	72.2
Gansu	3216	-0.0691	1.8008	136.8%	41.5
Shanxi	3216	-0.9152	1.8913	**147.7%**	41.6
Jiangxi	3217	-1.1853	2.0242	**151.5%**	52.1
Heilongjiang	3242	-1.1007	1.8672	134.6%	28.9
Henan	3265	0.1985	2.2979	<u>114.7%</u>	94.9
Guizhou	3298	0.4231	2.1550	136.4%	30.8
Ningxia	3430	-1.3484	2.3334	123.4%	48.2
Xinjiang	3442	0.3792	1.6349	127.7%	64.5
Hebei	3448	-0.7201	2.4158	138.0%	31.6
Jilin	3505	-1.4334	2.5334	**143.0%**	24.1
Anhui	3563	-1.5577	2.2178	130.3%	73.9
Hainan	3577	-2.0170	1.7458	142.5%	77.7
Shaanxi	3621	1.3188	1.3821	138.5%	49.7
Inner-Mongolia	3726	-0.5101	1.5677	121.4%	75.2
Hubei	3732	-0.2613	1.6840	121.6%	74.9
Yunnan	3785	-1.1615	2.9903	124.9%	95.2
Guangxi	3799	-1.0553	2.2325	**153.0%**	108.9
Sichuan	3803	-0.1352	2.5452	<u>120.3%</u>	78.0
Liaoning	3917	-0.7045	2.1801	129.7%	41.0
Hunan	3945	-3.2355	2.9852	125.3%	87.0
Shandong	4019	-0.4045	1.3637	127.2%	75.9
Chongqing	4370	-1.0654	1.7788	126.7%	48.6
Jiangsu	4497	-2.0932	2.0564	131.9%	152.8
Fujian	4667	-0.9372	2.6054	**147.1%**	112.2
Tianjin	5071	-1.3523	2.5022	<u>119.7%</u>	51.0
Zhejiang	5916	-1.8851	3.3026	139.2%	118.2
Guangdong	6110	-0.2912	2.4921	130.7%	124.8
Beijing	6453	-2.9353	2.8639	<u>120.9%</u>	75.1
Shanghai	7006	-2.3880	2.5487	<u>118.6%</u>	65.9
National Average	4069	-0.7980	1.8709	131.9%	57.9

Last but the most important, despite the exist of rebound effect, improving energy efficiency is still a useful measure in transportation because it can decrease the energy consumption of unit transportation service. To achieve the anticipate CO2 emissions reduction effects of energy efficiency improvement, some targeted accompanying policies should be considered to guide consumers’ behavior. We take carbon tax as a case to highlight how to achieve expected CO2 mitigation in each province via an integrated policy. Carbon tax, a kind of environmental taxes, provides incentives for carbon emissions reductions in various channels throughout the economy by putting a price on CO2 emissions. In addition, it is worth noting that the carbon tax might impose an extra burden on low income consumers. Thus considering the effectiveness of emissions reduction as well as benefit distribution, a differential carbon tax is a more promising policy.

We investigate that the carbon tax related to own-price and expenditure elasticities tends to be larger in rich provinces. That highlights the importance to implement differential accompanying policies in different provinces to realize equity among different income groups. Our results to some extent inform policy makers the degree of difference in carbon tax rate among provinces. We suggest policy makers to put special attention on the provinces with larger carbon tax rate such as Jiangsu, Zhejiang, Guangdong and Fujian, which need more strong measures to mitigate CO2 rebound effect.

Conclusions

This study reveal disparities of rebound effect among provinces, and show that provincial heterogeneity of rebound effect might be attributed to differences in economic development and the related differences in consumers' behaviors, especially the effects of "marginal consumers" and saturation. Carbon tax needed for dealing with rebound effect is related to own-price and expenditure elasticities, and tends to be larger in rich provinces which rationales the equity of carbon tax as a policy tool to address rebound effect. This paper is meaningful from energy and environmental policy viewpoints and is beneficiary for optimal policy design.