Urban Residential Energy Demand and Rebound Effect in China: A Stochastic Energy Demand Frontier Approach

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China is at the stage of rapid urbanization. The residential energy consumption has been dramatically increasing with the substantially rising population in urban regions. To combat climate change, China has made ambitious plans for energy demand control and energy conversion, including the control over residential energy consumption. According to those plans, one of the fundamental ideas is to improve energy use efficiency through different measures. However, the existence of the energy rebound effect might make the achievement of energy-use reduction plans in the residential sector full of uncertainty. Thus, estimating the energy rebound effect in China's urban residential sector is of importance for designing effective energy-saving policies. Also, China is a vast country with evident uneven development levels of regional economies. This motivates us to uncover the regional differences regarding the energy rebound effects, in order to understand the rebound effect in China's residential sector more profoundly and to provide some policy references for implementing the region-specific measures of energy conservation.

Based on the pioneering contribution of Orea et al. (2015) in the methodology, we estimate the energy efficiency and rebound effect in the urban residential sector for China's 30 provincial-level regions using an adapted stochastic frontier model, i.e., the stochastic energy demand frontier approach. This approach can simultaneously estimate the energy efficiency and energy rebound effect by one step. Thus, we can be free from the restrictions in the methods using price elasticity or using the proxy of energy efficiency change to improve the estimated accuracy of the rebound effect. Furthermore, we examine the influencing factors of residential energy consumption and identify the determinants of the rebound effect.

The results show that residents' income level, temperature deviation, population scale, and household size are positively correlated with urban residential energy consumption. On the contrary, the district heating system, energy price, and technology progress contribute to reducing residential energy consumption. Regarding the energy rebound effect, an inverted U-shaped relationship between residents' income level and rebound-effect size exists. Additionally, we find that energy price is negatively correlated with the rebound effect.

Regarding the magnitude of the rebound effect, the estimated values vary to a large extent across provinces and regions, with the first, median, and third quartiles approximately equal to 40%, 70%, and 95%, respectively. By grouping provincial-level regions based on their time average values of the rebound effect, we find the group with the largest rebound effect only consists of eastern and developed provincial-level regions. In contrast, the group with the smallest rebound effect mainly consists of northwest and northeast provincial-level regions that are relatively poor. Furthermore, there is an evident "north-south" difference in the rebound effect size. For instance, the central north region and central south region are geographically nearby regions and similar in both the level and growth rate of residential income. However, the average regional size of the rebound effect increases to a large extent from the central north (42.19%) to the central south (70.32%).

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Some important policy implications can be raised based on our main findings. First, energy pricing reform may be the most helpful policy tool since the marketization of energy prices in China is far from sufficient. Second, local governments should replace their GDP-based targets with sustainable development goals as proposed by the United Nations. Third, urban energy conservation in China needs the assistance of climate change mitigation policies, which aim to avoid dramatic temperature changes, to achieve a synergic outcome of these two types of policies.