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Decomposition of rebound effect: An energy-specific, general equilibrium analysis in the context of China

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HIGHLIGHTS

- Energy-specific, macro-level rebound effect is decomposed into sector level.
- Sector rebound effect is decomposed into output effect and substitution effect.
- Final demand leads to more rebound in secondary energy than in primary energy.
- Rebound in an energy is mainly caused by the big users of this energy.
- Energy producing sectors contribute negatively to rebound.

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ABSTRACT

The objective of this study is to trace and quantify the sources of rebound effect for different energy sources in China. This paper decomposes the economy-wide rebound effect into 135 production sector-level rebound effects and five final demand components. The sector-level rebound is further decomposed into output effect and substitution effect. A two-stage decomposition method and a static computable general equilibrium model are developed to achieve this. Five types of energy-specific efficiency improvements are introduced, respectively, in all the production sectors. Results show that improving efficiency of using coal leads to the smallest macro-level rebound. For rebound decomposition, four findings are generalized. First, final consumption shows larger impact on the rebound of secondary energy sources than on primary energy sources. Second, production sectors that are big user of the efficiency-exposed energy source are expected to be key rebound contributor. Third, energy-producing sectors make negative rebound contribution. Results also show that, substitution effect is the predominant mechanism that triggers sector-level rebound. Policy implications are also discussed.

1. Introduction

Improving energy efficiency is a powerful and cost-effective tool to promote green growth as well as reduce emissions. The International Energy Agency (IEA) estimates that 40% of necessary greenhouse gas emissions reductions will have to come from energy efficiency by 2050 for limiting global temperature increase to 2 °C [1]. However, there are important claims that expected energy saving benefits are often not fully realized from energy efficiency measures, because improved efficiency gains are counter-balanced by increased consumption and expenditures, the so-called 'rebound effect'.

This concept is first known as 'Javons Paradox' [2] and then 'Khazzoom–Brookes' postulate [3–5]. Over the 40-or-so years since Khazzoom, the rebound literature has resulted in a wide agreement of its existence. Three types of rebound effect are generally distinguished in the literature: direct, indirect and the macroeconomic or economy-wide rebound effect [6–8]. Wei and Liu [9] summarized that direct and indirect rebound effects refer to changes in sector-level energy

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consumption assuming no effect on other sectors and market prices. Economy-wide rebound effect refers to the taken-back effect at regional/global level which considers general equilibrium response to efficiency improvement. Notably, as pointed out by previous studies [10–13], rebound on the macroeconomic level is important and deserves more research, because it concerns the whole economy and covers all possible channels.

Many has investigated the rebound effect at macro-level. However, most focused on measuring to what extent energy savings are taken back. Substantially, less efforts have been put into interpreting the sources of rebound effect. Trace and quantify the causal factors behind rebound effect is crucial to the effectiveness of energy efficiency policy. Indeed it should be an integrated part of any cost-benefit analysis of energy efficiency policies. Turner [14] also pointed out that getting better understanding of the mechanisms of rebound effect is more important than measuring the magnitude of it. This study, therefore, contributes to the literature in this regard by providing new insights into the major mechanisms behind rebound effect.

Investigating the issue in China has broad implications, as China is a dominant energy consumer in global context and also a forerunner in climate and energy policies. The Chinese government has always been considering improving energy efficiency as an important policy in its energy and climate change policy package (e.g. [15,16]). From the 11th Five-Year-Plan to the most recent 13th Five-Year-Plan, the government keeps stating that the energy efficiency should be continuously improved, especially the energy-intensive industries and the efficiency of using coal. The government has set ambitious goals to increase energy efficiency. As planned, the energy efficiency of at least 80% of industrial sectors should have arrived at its advanced counterparts by 2020. However, previous work for China has suggested strong presence of rebound effect (e.g. [17–22]). In fact, Glomsrød and Wei [23], Liang et al. [24], Shao et al. [25] and Li et al. [26] find extremely large rebound magnitudes (backfire) in China. These highlights the importance of knowing what factors contribute to such results and how significant these contributions are.

Our central aim is to trace the economy-wide rebound back to sector level and identify the contributions. We achieve this by developing a novel, two-stage decomposition approach based on the computable general equilibrium (CGE) model. On the macro level, we decompose the economy-wide rebound effect by energy users, including 135 production sectors and five final demand components. On the sector level, we further break down the sector rebound into output effect and substitution effect.

In addition to the timely policy relevance, this paper contributes to the literature in the following aspects. First, this is, to the knowledge of the authors, the first study to decompose the economy-wide rebound effect into highly disaggregated sector level. This not only allows us to identify the main contributors to economy-wide rebound, but also their mechanisms. One highlighted implication is that the mechanisms of rebound effect triggered can be very different across different sectors, which means some sectors can be remarkable contributors to the economy-wide rebound. Therefore, the energy efficiency policy would be more effective if ex ante measures can be taken to offset those major rebound channels.

Second, this study adds some evidences on the choice of effective energy efficiency technologies. The rebound literature has focused on discussing rebound effect of improving efficiency of the energy composite. In fact, energy efficiency policies are likely to be energy-specific, for example, the Chinese government pays particular attention to improving efficiency of using coal. Moreover, Lu et al.'s [27] recent study suggested that the rebound effect of different energy sources can vary markedly. It is of practical importance to choose more effective energy efficiency technologies. Therefore, this paper investigates rebound effect for different types of energy-specific efficiency improvement, including coal (Coal), crude oil and natural gas (OilGas), refined petroleum (PetrolRef), electricity (Electricity), and gas supply (GasSupply).

Finally, the methodological contribution of this article – a new, two-stage method to trace and quantify the sources of rebound effect in a CGE framework – are of relevance for studies of rebound effect for other economies. This can be readily applied in CGE exercises of other countries to precisely identify the country-specific major mechanisms behind rebound.

The rest of the paper is organized as follows: the next section provides a brief review of the literature; the modelling approach will be illustrated in Section 3; the simulation results will be reported and discussed in Section 4; Section 5 concludes with policy implications.

2. Literature review

Rebound effect has already been extensively examined by a variety of methods, at different system boundary, with different time frame. Excellent reviews can be found in the existing literature, for example, Greening et al. [28], Sorrell [11], Van den Bergh [12], Turner [14], and Gillingham et al. [29]. Therefore, only those that are related to our study will be reviewed here.

No study has discussed the decomposition of the economy-wide rebound, except Koesler et al. [30]. Using a CGE model, Koesler et al. [30] decomposed the rebound effect for Germany into a production-side rebound effect and a consumption-side component. They found a positive contribution of final demand to total rebound. However, their focus is to investigate the spill-over effect of German industrial energy efficiency improvement to household/global energy consumption and didn't further decompose the production-side rebound into sector level. Lu et al. [27] provided a similar decomposition by adopting Koesler et al.'s [30] approach. Theirs therefore does not give the contribution of various sector to the macro-level rebound and thus cannot provide a deeper insight on mechanisms that governing macro-level rebound.

Nevertheless, a few attempts have been made to link sector heterogeneity to the magnitude of economy-wide rebound. Among these studies, some focused on investigating the economy-wide rebound effects of multiple single-sector energy efficiency improvement scenarios. For instance, by comparing the impacts of a 5% increase in energy efficiency occurs in each of 11 sectors individually, Liang et al. [24] found a large macro-level rebound when efficiency increase occurs to transportation sector. Hanley et al. [31] directed the 5% efficiency shock at different sub-sets of sectors to test the variations in macro-level rebound effect. They found a much larger rebound when the efficiency gain is restricted to energy sectors. More recently, Yu et al. [32] simulated 69 sector-specific energy efficiency improvements for Georgia, USA. They indicated large macro-level rebound when the efficiency increase occurs to an energy production sector, a direct upstream/downstream sector of energy production sector, a transportation sector, or a sector with high production elasticity.

Differently, some studies explored the heterogeneity on rebound contributions across sectors by looking at the sector-specific overall rebound effect rather than rebound effect of the whole economy. For example, using a Sweden CGE model, Broberg et al. [33] estimated 27 sector-specific rebound effects under a uniform energy efficiency improvement scenario and concluded that it is not wise to target energy-intensive sectors in energy efficiency policies due to its relatively high rebound effect. Using a similar approach but in a global CGE model, Wei and Liu [9] found in the long run the highest rebound effect of 91% in agriculture, lowest of 61% in the household sector and is about 74% in cement, iron & steel, and transport sector. Contrast to Broberg et al. [33], Wei and Liu [9] argued that energy efficiency improvement seems more effective for energy-intensive sectors. Li and Lin [34] estimated 21 sector-specific overall rebound effects over 2006–2010 for China based on an input-output analysis. Li et al. [20] used an output distance function to estimate the overall rebound effect across energy-intensive industries for China over 1998–2011. Both Li and Lin [34], and Li et al. [20] recommended varies strategies among sectors due to heterogeneity in rebound effects.

These studies, although affirming the heterogeneity on sectoral contribution to economy-wide rebound, have different specific aims and do not particularly tracing the sources of economy-wide rebound back to sector level. Furthermore, they are not systematic decomposition of economy-