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Rebound effect of improved energy efficiency for different energy types: A general equilibrium analysis for China

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ABSTRACT

This paper explores the rebound effect of different energy types in China based on a static computable general equilibrium model. A one-off 5% energy efficiency improvement is imposed on five different types of energy, respectively, in all the 135 production sectors in China. The rebound effect is measured both on the production level and on the economy-wide level for each type of energy. The results show that improving energy efficiency of using electricity has the largest positive impact on GDP among the five energy types. Inter-fuel substitutability does not affect the macroeconomic results significantly, but long-run impact is usually greater than the short-run impact. For the exports-oriented sectors, those that are capital-intensive get big negative shock in the short run while those that are labour-intensive get hurt in the long run. There is no "backfire" effect; however, improving efficiency of using electricity can cause negative rebound, which implies that improving the energy efficiency of using electricity might be a good policy choice under China's current energy structure. In general, macro-level rebound is larger than production-level rebound. Primary energy goods show larger rebound effect than secondary energy goods. In addition, the paper points out that the policy makers in China should look at the rebound effect in the long term rather than in the short term. The energy efficiency policy would be a good and effective policy choice for energy conservation in China when it still has small inter-fuel substitution.

1. Introduction

Improving energy efficiency is one of the most important and well-accepted policies for energy conservation. The ideology of it is straightforward and intuitive: by improving energy efficiency, one can produce the same amount of output using less energy; and therefore, it reduces energy demand. In recent years, the policy for improving energy efficiency has been widely used in some European countries, such as UK; however, the effectiveness of this policy, stemmed from the so-called "rebound effect", has also been challenged by researchers (e.g. Turner, 2013).

The Chinese government has always been considering improving energy efficiency as an important policy in its energy and climate change policy package. During the 11th "Five-Year-Plan" period, the energy efficiency of the 8 major industries and the 14 products narrowed the gap between advanced economies by about 20 percentage point from 2000 to 2007.[1] In the 12th "Five-Year-Plan", the government also stated that the energy efficiency of the industrial sectors should be continuously improved, especially the coal-fired electricity industry. There are many policy instruments being used to improve energy efficiency. For example, the Chinese government has set efficiency standards and different power prices on high energy-consuming industries; and the power plants with low efficiency have been restrained, transformed or even closed. Indeed, the energy efficiency in China has much potential to be alleviated compared to its advanced counterparts. Improving energy efficiency is also an important aspect in technological development. However, the rebound effect of these policies has attracted many studies and policy debate by Chinese researchers (e.g. Wang et al., 2014; Lin and Li, 2014).

The energy rebound effect refers to the effect that any anticipated energy saving from improved energy efficiency may be partly or wholly offset or even surpassed (called "backfire") by the increase of energy demand (see e.g. Brookes, 1990; Herring, 1999; Birol and Keppler, 2000; Saunders, 1992, 2000, 2008; Turner, 2009). This concept originally arose from the so-called "Jevons" Paradox" (Jevons, 1865), later it was discussed in Brookes (1978), Khazzoom (1980) and Saunders (1992). It is initially observed and measured on the micro level, which is classified by Greening et al. (2000) as direct rebound effect. Following Greening et al. (2000), direct rebound refers to the increase of energy demand due to reduced prices of energy services caused by energy efficiency improvement in the use of a physical energy input, which should

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[1] This was reported on China Daily (June 3, 2010): http://finance.people.com.cn/GB/11768935.html.

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have reduced the amount of energy required to produce the energy services. Other than direct rebound effect, there are different classifications of the rest of the effect.[2] In particular, the scope of the rebound effect has been recently extended even to the world-wide level (see e.g. Wei, 2007, Barker et al., 2009; Koesler et al., 2014, 2016). As Gillingham et al. (2013) pointed out, the rebound on the macroeconomic level deserves more research in this area. More recently, Vivanco et al.'s (2016) study suggested that the analysis of rebound effect in the energy field can contribute to a general framework in analysing other environmental policies. However, the size of the rebound effect estimated in the literature covers a wide range, from negative (e.g. Turner, 2009) to more than 100% (e.g. Semboja, 1994; Hanley et al., 2009; and also see Dimitroulos (2007) for a review).

Notably, Van den Bergh (2011) argued that (energy) rebound effect is particularly relevant for developing countries. He provided various reasons, and one of which is that the energy cost is relatively higher in developing countries due to its cheap labour cost. Another reason is that a large potential to improve energy efficiency may lead to more use of energy-efficient technologies as well as new energy-using devices (Van den Bergh, 2011). Therefore, China, as a large developing country that puts great efforts in improving its energy efficiency across industries, should be alerted to the implications of such policies.

Research interests on measuring rebound effect for China started around 2005. In Glomsrod and Wei's (2005) CGE study on the impact of coal cleaning on pollutant emissions in China through increasing energy efficiency, they found a rebound effect of energy consumption larger than 100% (i.e. backfire). After Glomsrod and Wei's (2005) study, the rebound effect studies for China focused on three aspects: (1) region-specific or sector-specific rebound effect (e.g. Wang et al., 2012, 2014; Lin and Li, 2014); (2) from short-run effect to long-run effect (e.g. Guo et al., 2010; Li and Lu, 2011; Shao et al., 2014); and (3) specific policy evaluation and selection (e.g. Liang et al., 2009; Lin and Liu, 2013; Li et al., 2013). In terms of methodology, most of the above studies adopt econometric approaches while Li et al. (2013) uses Input–Output analysis framework, and Glomsrod and Wei (2005), Liang et al. (2009) and Li and Lu (2011) adopt CGE modelling approach.

However, in terms of economy-wide rebound effect, these studies provide various results. Guo et al. (2010) estimated the industrial rebound for China to be 46.38% from 1979 to 2007 while Xue (2014) found that the rebound for the household energy consumption in China is only 0.27% in the long run and 0.16% in the short run. Li and Lu (2011) even found the rebound effect for China to be 178.61% in the long run. Shao et al. (2014) estimated that the rebound effect in the recent decade was −11.36% in the short run and 71.63% in the long run.

In addition, most studies, including studies in other countries, focus on the rebound effect of the aggregate energy consumption. They neither distinguish nor compare different energy types. However, this is a relevant and important policy issue of choosing more effective energy efficiency technologies. For example, the rebound effect of improving energy efficiency of using coal can be very different from that of improving energy efficiency of using electricity. Therefore, our study explores energy rebound effect in three dimensions by using a China CGE model: energy types, model closure (short-run versus long-run) and inter-fuel substitutability. Despite the timely policy relevance of the issue, this paper contributes to the literature and the relevant policy-making in China in the following aspects.

First, this is, to the knowledge of the authors, the first study for China to specifically measure the economy-wide rebound effect by different energy types (i.e. coal, crude oil and gas, refined petroleum, electricity and steam supply and gas supply) in a comprehensive CGE model. CGE model is a suitable tool in measuring economy-wide rebound effect as it can reflect different mechanisms of rebound effect triggered across different sectors and on different levels.

Second, due to the detailed modelling of industrial sectors of Chinese economy in this study (135 sectors), we are able to measure and decompose the economy-wide rebound effect and explore the mechanisms of this rebound effect across the economy. Although it is an empirical study for China, it helps to better understand the rebound mechanism on the economy-wide level in a broader sense, which is a major unresolved problem in this area identified by Turner (2013).

Finally, this study provides some new and insightful implications in terms of energy efficiency policies. One highlighted implication is that the triggered rebound effect can be very different for different energy types, which means improving energy efficiency might be relatively costly (i.e. rebound is very large) for some energy type in the current economic structure; therefore, it might not be a good policy option to improve energy efficiency in using this type of energy while improving the energy efficiency of using another type would be more effective.

The rest of the paper is organized as follows: the modelling approach will be illustrated in Section 2, including a brief description of the CGE model used in this study and how the rebound effect is measured and decomposed; then Section 3 will describe the design of our simulation scenarios; the simulation results will be reported and discussed in Section 4; then Section 5 concludes with policy implications.

2. Modelling approach

2.1. Measurement of rebound effect

There is much discussion on how to measure rebound effect. Following Greening et al.'s (2000) classification of rebound effect, in this paper, we focus on the macro-level or economy-wide rebound effect rather than the micro-level one. The measurement definition by Saunders (2000, 2008) is the most widely used one for macro-level rebound effect. Therefore, rebound effect R is measured as:

$$R = 1 + \eta^{F}_{\tau_F}, \quad \text{where} \quad \eta^{F}_{\tau_F} = \frac{d\ln F}{d\ln \tau_F}, \tag{1}$$

in which $\eta^{F}_{\tau_F}$ is the "fuel use" which is the elasticity of fuel use F with respect to the fuel efficiency gain τ_F; and R is the percentage measure of this rebound. If $R = 0$, then there is no rebound; if $R = 1$, then there is 100% rebound. In particular, the backfire occurs when $R > 1$.

Following Turner (2009) and Hanley et al. (2009), Turner (2013) explores the theoretical presentation of rebound effect that can be applied in a CGE model in which she distinguishes between energy measured in physical units and in efficiency units. Therefore, the rebound effect can be derived as:

$$R = \left[1 + \frac{\dot{E}}{\rho}\right] \times 100 \tag{2}$$

in which $\dot{E} = \frac{\Delta E}{E}$ is the rate of change of energy used corresponding to the energy augmenting technical progress rate ρ. Actually, ρ is usually the autonomous energy efficiency improvement (AEEI) shock imposed in

[2] For example, Greening et al. (2000) identified four types of rebound: direct rebound effect, secondary fuel use effect, economy-wide effect and transformational effect. Gillingham et al. (2013) classified rebound as: direct, indirect and macroeconomic rebound. Actually, the secondary fuel use effect in Greening et al. (2000) is what Gillingham et al. (2013) called "indirect rebound effect". It is the increase of energy consumption resulting from saved income (cost) spent on other energy-using goods and services. Economy-wide or macroeconomic rebound effect refers to the widespread impact on the equilibrium prices and outputs of other goods resulting from the efficiency improvement of certain energy goods and services. Greening et al. (2000) also distinguish the transformational effect as the potential change of consumers' preferences, social institutions, and the organization of production due to the change of energy efficiency improvement technology. In this paper, our measurement of rebound effect mainly focuses on the economy-wide effect while the mechanisms of direct and indirect effect are used to explain the results. However, the transformational effect is not considered in this paper.