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Rebound effect by incorporating endogenous energy efficiency: A comparison between heavy industry and light industry

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HIGHLIGHTS

- Incorporating endogenous energy efficiency into the model specification of rebound effect.
- Rebound effect is decomposed into substitution component and output component.
- Comparing rebound effect of heavy industry and light industry by considering heterogeneity across sub-industries.
- Evolution of rebound effect may be explained by energy supply conditions.
- Highlighting policy application via combining energy subsides and technological progress with rebound effect.

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ABSTRACT

Energy resource depletion and environmental degradation have become big challenges for China's sustainable development. Energy efficiency improvement is usually regarded as an major pathway for reducing the pressure on energy and the environment. However, this would be undermined by the rebound effect, because the rebound effect would partially or even totally offset the anticipated of efficiency improvement. Evidence of the rebound effect has important implications for the economic, resource and environmental consequences of improving energy efficiency, as well as enables policy makers to take informed decisions on energy and environmental issues. In this paper, we incorporate the endogenous energy efficiency into the model specification of rebound effect, and build a unified comprehensive framework for analyzing rebound effect and related issues. We applied this framework to conduct empirical analysis and comparison of heavy and light industries, considering heterogeneity across sub-industries. Furthermore, this paper goes beyond simple estimation of rebound effect, and takes additional effort to highlight the policy application via combining energy subsidies and technological progress with rebound effect.

1. Introduction

China is the largest energy consumer in the world and accounts for 23% of global energy use [1]. Fig. 1 displays the historical trends of energy consumption in China. For comparison, energy consumptions in the US, European Union (EU) and India are also presented. Energy use in China experienced a large increase from 397 million tonnes oil equivalent (Mtoe) to 2972 Mtoe during 1978–2014, with an average growth of 5.7% per year. This growth is more than fourth times faster than the average growth worldwide during the same periods. Especially, China has re-oriented towards heavy industrialization since 2003 and the growth of energy consumption has been accelerated (as also shown in Fig. 1).

Due to energy resource depletion, energy security issues and global call for CO_2 emission reduction, energy conservation is believed to be a central issue in China's sustainable development. Energy saving technology is usually regarded as the most important option of reducing energy consumption. However, there is a paradox between engineering efficiency gains and energy consumption in China. ***On the one hand***, China has achieved dramatic progress in energy-saving technology. For example, the energy consumption rate of coal-fired power plants declined by 24% between 1990 and 2012; and energy consumption per unit of steel declined by 32% during this period. Electricity supply and steel sectors account for approximately 47% of China's total primary energy

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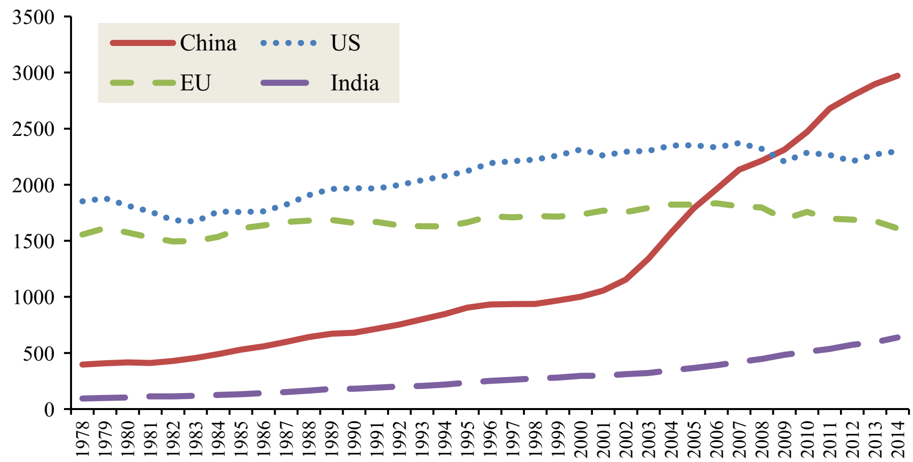

Fig. 1. Energy consumption after China's reform and opening up in 1978 (Unit: Mtoe). Source: British Petroleum [54].

consumption. For comparison, the equivalent for Japan are 8% and 3%, respectively. The dramatic efficiency gains in engineering of these two sectors provide a brief overview of China's energy-saving technological progress. ***On the other hand***, it seems that the growth of China's energy consumption has not been decelerated by energy saving technology. Energy consumption in 2012 increased three times compared with 1990. This paper attempts to provide a potential explanation for this paradox from the perspective of rebound effect.

Improvements in energy efficiency would reduce the real price of energy services by decreasing the amount of energy required to produce products. Thus energy efficiency improvement encourages energy consumption through two effects [2]. First, an efficiency induced price reduction in energy service would shift the mix of factor inputs by substitution between energy and other inputs, and thus increase energy demand for a given output. Second, improvements in energy efficiency reduce the marginal cost of producers and consequently sales price, which would further encourage additional energy demand because of expanded production. The two effects make energy efficiency improvements not as effective as originally expected. Therefore, the rebound effect can be defined as the lost part of energy conservation which is offset by increased energy consumption. For example, a rebound effect of 10% indicates that 10% of energy conservation due to efficiency improvement is mitigated by factor substitution or by output expansion.

If the rebound effect is large in China, it is totally possible that the reduced energy service price through energy efficiency improvement might encourage energy consumption and totally offset energy saving potentials. Thus, the magnitude of the rebound effect in China is crucial for implementing energy saving policies, and the purpose of this paper is to conduct an empirical research on China's rebound effect.

Industrial energy consumption accounted for approximately 70% of aggregate energy consumption. The magnitude of the rebound effect in the industrial sector is crucial to the country's energy conservation. It should be noted that there is heterogeneity in production functions among different industrial sub-sectors. Thus these sub-industries are generally divided into two groups: heavy industry and light industry. According to the classification method of Chinese National Bureau of Statistics (CNBS), the former refers to industries that are involved with large and heavy products such as coal, oil, iron, ships; or large and heavy facilities and equipments; while the latter represents industries that are typically characterized by more consumer-oriented goods, such as the manufacturing of furniture, clothes and home appliances. This classification usually reflects the relative energy-intensity of the manufacturing processes [3]. The former is more energy (and capital) intensive while the latter is more labor intensive. This characteristic might have significant meaning for determining the magnitudes of their rebound effects, especially for the output effect, because the decrease in price of energy service lowers the marginal cost of heavy industry products more significantly due to larger energy cost share in the heavy industry.

Furthermore, the rebound effect is tightly connected with energy subsidies [4], because energy subsidies depress energy prices. In China, energy prices are regulated or even directly controlled by government. To accelerate economic growth, energy prices have been continuously undervalued through energy subsidies. Although the scale of energy subsidies have decline due to reforms in the energy market, it is still large [5]. Thus, the removal of energy subsidy would reduce the magnitude of the rebound effect.

The main contributions of our paper lie in the following four aspects. First, energy efficiency is endogenous to the model for measuring rebound effect. Because rebound effect is a concept tightly connected with energy efficiency, specifying it by incorporating endogenous energy efficiency could provide a unified framework. Second, the rebound effect is decomposed into substitution component and output component. It helps us to reveal the mechanisms of the rebound effect more clearly. Third, considering the heterogeneity of sub-industries, we measure and compare the rebound effect of heavy industry and light industry, rather than the aggregate rebound effect of the whole economy assuming all sectors as homogenous. Due to their different energy consumption characteristics, it is more in line with the reality of China's industry to regard heavy industry and light industry separately. Finally, this paper goes beyond simple estimation of rebound effect, and takes additional effort to highlight the policy application via combining energy subsidies and technological progress with rebound effect.

The reminder of this paper is organized as follows. We briefly provide an overview of the existing studies in Section 2, especially on the controversy in the magnitude of the rebound effect. The methodology is presented in Section 3. In Section 4, the dataset is described and the empirical results are discussed. Section 5 details further discussion of the rebound effect combining energy subsidies and technological progress. In Section 6, we conclude the findings and offer policy implications.

2. Controversy in the magnitude of rebound effect: A literature review

Rebound effect was first proposed by Jevons [6], and then gradually became a subject of intensive studies in recent years,