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The macroeconomic rebound effect in China☆

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ABSTRACT

The rebound effect measures the fraction of an energy efficiency improvement that is offset by increased energy consumption. A rebound effect can arise at both the microeconomic level and the macroeconomic level. The macroeconomic rebound effect measures the effect of an increase in energy efficiency on overall energy demand after markets adjust and re-equilibrate. At the macroeconomic level, energy efficiency gains can increase energy consumption through two channels: the macroeconomic price effect and the macroeconomic growth effect. In this paper, we econometrically estimate the macroeconomic energy rebound effect in China. Our results show that there is a statistically significant macroeconomic price rebound effect for China, for each province, and for the short run, intermediate run, and the long run. We also find some evidence of a macroeconomic growth rebound in the short run and the intermediate run for some years either nation-wide or for some provinces in China; moreover, for some years and some provinces, we cannot reject backfire. The rebound effect is an important phenomenon that the government of China should not neglect when making energy policy, as it affects how improvements in energy efficiency translate into changes in energy consumption.

1. Introduction

Energy plays an important role in economic growth. However, the consumption of energy, particularly fossil fuel sources of energy, is associated with many problems including climate change and pollution. One possible way to reduce the greenhouse gas emissions and pollution caused by energy consumption without curbing economic growth is to increase the efficiency with which we use energy. At first blush it may seem intuitive that improving the efficiency of energy use will lead to a reduction in energy consumption. Evidence from history and empirical research shows, however, that the actual savings in energy consumption from an increase in energy efficiency can be less than the expected savings. A “rebound” effect arises when some of the gains from improving the efficiency of energy use are lost because of behavioral responses (Gillingham et al., 2013).

Energy-related issues are particularly acute in developing countries such as China, where energy consumption has been increasing rapidly, resulting in energy-related problems such as power shortages and environmental pollution (Si et al., 2017b). The International Energy Agency (2014) estimates that half of the world oil demand growth till 2035 is likely to come from China overtaking the U.S. as the world's biggest oil consumer (Si et al., 2017a). In 2011, China's CO_2 emissions constituted 29% of world CO_2 emissions (EDGAR, 2014; Si et al., 2017a). Policies that increase energy efficiency may seem to be one possible way to reduce the greenhouse gas emissions and pollution caused by energy consumption in China. However, owing to possible rebound effects, energy efficiency policies may be ineffective, or even have perverse consequences. Rebound effects in China therefore have important implications for policy.

A rebound effect can arise at both the microeconomic level and the macroeconomic level (Gillingham et al., 2016). The purpose of this paper is to estimate the size of China's macroeconomic rebound effect.

The rebound effect measures the fraction of an energy efficiency improvement that is offset by increased energy consumption. The macroeconomic rebound effect measures the effect of an increase in energy efficiency on overall energy demand after markets adjust and re-equilibrate (Gillingham et al., 2016). At the macroeconomic level, energy efficiency gains can increase energy consumption through two channels. The first channel for the macroeconomic rebound effect is the macroeconomic price effect: an energy efficiency improvement shifts the market demand curve for energy in, and consumers and producers will adjust until a new equilibrium is reached. The second channel for the macroeconomic rebound effect is the macroeconomic growth effect: an increase in energy efficiency can spur economic growth, either through a reallocation of growth through sectoral reallocation or overall growth

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through an increase in total factor productivity, and the economic growth requires additional energy consumption (Gillingham et al., 2016).

The macroeconomic rebound effect was first hypothesized by Jevons in his classic 1865 book The Coal Question (Jevons, 1865). In honor of Daniel Khazzoom and Leonard Brookes's seminal work on the rebound effect (Khazzoom, 1980, 1987; Brookes, 1978), Saunders (1992) put forward the Khazzoom–Brookes postulate, which suggests that energy efficiency improvements might increase rather than decrease energy consumption, a phenomenon known as "backfire" that is represented by a rebound effect >1 (Sorrell, 2007).

Much of the theoretical and empirical literature on the rebound effect has focused on the microeconomic rebound effect in the residential sector and the transportation sector (Gillingham et al., 2016 & references therein; Chan and Gillingham, 2015; Borenstein, 2015; Greening et al., 2000; De Borger et al., 2016). According to Sorrell (2009), however, the macroeconomic rebound effect was Jevons' (1865) primary concern.

Few economists would deny that there exists a macroeconomic rebound effect in the real economy. But there is a debate over the magnitude of the rebound effect among energy economists. Dimitropoulos (2007) presents a comprehensive survey of the previous research in this area. Binswanger (2001) finds in his survey of empirical studies that the estimated size of the rebound effect varies with the method and data employed in the studies, and ranges from 5% to 50%.

The macroeconomic rebound effect is often estimated using computable general equilibrium (CGE) models (Barker et al., 2007a). The advantages of CGE models are that they are detailed, complex, and comprehensive. The drawbacks are that CGE models have may several limitations, including market and behavioral assumptions that may not be supported by empirical evidence, restrictive functional form assumptions, and sensitivity of the results to the base year chosen for the calibration and to assumed parameter values (Gillingham et al., 2016; Sorrell, 2007). Of the eight CGE modeling results surveyed by Sorrell (2007), all find a macroeconomic rebound effect >37% and most studies showed macroeconomic rebound effects >50%.

Turner (2009) uses a computable general equilibrium model to estimate the rebound effect in the UK, and finds evidence for a net negative economy-wide rebound effect as a result of the reduced intermediate energy input requirement of Scottish production sectors where efficiency increases in industrial energy use (Turner, 2009, 2013). Using a computable general equilibrium model, Barker et al. (2007b) find that the macroeconomic rebound effect arising from UK energy efficiency policies for the period 2000–2010 is around 11% by 2010, averaged across sectors of the economy. Barker et al. (2009) use a sectoral dynamic macroeconomic computable general equilibrium model of the global economy to estimate the macroeconomic rebound effect. Grepperud and Rasmussen (2004) use a general equilibrium model to analyze the rebound effect in Norway.

In contrast to a computable general equilibrium model, a more parsimonious econometric model may have the advantages of being less sensitive to the many assumptions needed for a CGE model, and of estimating parameters econometrically from data. Adetutu et al. (2016) estimate economy-wide rebound effects using a combined stochastic frontier analysis and two-stage dynamic panel data approach, and find that in the short run, a 100% energy efficiency improvement is followed by a 90% rebound in energy consumption, but that in the long run it leads to a 136% decrease in energy consumption.

There have been some previous studies estimating the rebound effect in China. Zhou and Liu (2007) estimate the rebound effect of China's energy consumption from 1979 to 2004, and find that there are large differences in the magnitude of rebound effect from year to year. Guo et al. (2010) estimate the rebound effect of energy consumption in industrial sectors in China. Liu and Liu (2008) find that the size of rebound effect in China is declining from 1985 to 2005. Li and Han (2012) calculate the energy rebound effect for three industries in China over the period 1997–2009. Zhang et al. (2017) estimate the energy rebound effect in the industrial sectors in China. Lu et al. (2017) use a CGE model to measure the rebound effect of different energy types in China.

In this paper, we build on the previous literature on the rebound effect and on the rebound effect in China by econometrically estimating the macroeconomic energy rebound effect in China. We contribute to the literature by estimating the macroeconomic energy rebound effect using an econometrical model rather than a computable general equilibrium model; by estimating the macroeconomic energy rebound effect in China at both the national and province levels; by estimating the macroeconomic energy rebound effect in China over multiple time horizons (short run, intermediate run, and long run); and by estimating not only the macroeconomic rebound effect but also its two constituent effects (the macroeconomic price effect and the macroeconomic growth effect).

Evidence for or against a rebound effect is obscured in energy/GDP ratios (Saunders, 2000a). One strength of our methodology and analysis is that we do not require either data on energy efficiency or the assumption that energy efficiency is given by the energy/GDP ratio. Instead, in order to estimate the macroeconomic rebound effect, price effect, and growth effect, we derive analytic expressions for the macroeconomic rebound effect, price effect, and growth effect from a production function. These analytic expressions for the macroeconomic rebound effect, price effect, and growth effect that we derive are functions of production function parameters, output, and energy consumption, and do not assume that energy efficiency is given by the energy/GDP ratio. We estimate the production function parameters econometrically using data on output, capital, labor, and energy consumption.

To further analyze the macroeconomic growth rebound effect, we derive an analytic expression for the macroeconomic growth rebound effect based on a definition of the growth rebound effect as a function of actual energy savings (AES) and potential energy savings (PES). This analytic expression for the macroeconomic growth effect is a function of total productivity (which we estimate econometrically using data on output, capital, labor, and energy consumption), output, and energy consumption, and captures the channel that an increase in energy efficiency can spur economic growth through an increase in total factor productivity, and the economic growth requires additional energy consumption.

Our methodology for estimating the macroeconomic rebound effect, price effect, and growth effect therefore only requires data on output, capital, labor, and energy consumption, and does not require either data on energy efficiency or the assumption that energy efficiency is given by the energy/GDP ratio.

Our results show that there is a statistically significant macroeconomic price rebound effect for China, for each province, and for the short run, intermediate run, and the long run. We also find some evidence of a macroeconomic growth rebound in the short run and the intermediate run for some years either nation-wide or for some provinces in China; moreover, for some years and some provinces, we cannot reject backfire. The rebound effect is an important phenomenon that the government of China should not neglect when making energy policy, as it affects how improvements in energy efficiency translate into changes in energy consumption.

The balance of our paper proceeds as follows. We discuss the macroeconomic rebound effect in Section 2. We describe our methods in Section 3 and our data in Section 4. We present our results in Section 5. Section 6 concludes.

2. Macroeconomic rebound effect

The macroeconomic rebound effect measures the effect of an increase in energy efficiency on overall energy demand after markets adjust and re-equilibrate (Gillingham et al., 2016). At the macroeconomic