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Measuring plant level energy efficiency in China's energy sector in the presence of allocative inefficiency

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ABSTRACT

Most studies on measuring China's energy efficiency were conducted in the framework of the input-oriented Data Envelopment Analysis. This approach generally calculates the technical efficiency by shrinking all the input factors equally proportionally subject to the observed output still being producible. Thus, all the input factor efficiencies, including the energy efficiency, are measured as the technical efficiency. One drawback of this approach is the presumption of an identical input factor frontier for all input factors and of unrestricted factor substitutability. The present study employs a stochastic frontier analysis approach to measuring energy efficiency that not only allows for non-identical input factor frontiers, but also controls for the effects on the measure of energy efficiency of substitution away from energy or substitution of energy for non-energy factors. This approach is applied to evaluating the efficiency performances of three types of energy amongst a sample of coal mines, petroleum refineries and power plants in China's energy sector which is specifically targeted by the Chinese government to improve energy efficiency.

1. Introduction

China's environmental challenges and increasing dependence on energy imports have prompted the Chinese government to strive for improvement of energy efficiency and reduction of energy intensity. Therefore, assessment of China's energy efficiency has attracted a lot of attention, for example, He, Zhang, Lei, Fu, and Xu (2013), Wu, Fan, Zhou, and Zhou (2012), Su, Zhou, Nakagami, Ren, and Mu (2012), Shi, Bi, and Wang (2010), Li and Hu (2012), Yang, Yang, and Chen (2011), and Wei, Ni, and Shen (2009), just to name a few. These studies show, amongst other things, that energy efficiency performances vary conspicuously between sectors and regions. For example, the He et al. (2013) study that is concerned with energy efficiency in the iron and steel industry shows that the average energy efficiency at the industry level was 61.1% on average over the period 2001–2008. This is in contrast to 81.6% on average over the period 1997–2008 for the industrial sector (Wu et al., 2012). Such a big difference prompts further studies on energy efficiency performances in other sectors to provide a more comprehensive understanding of energy efficiency in China. The present paper measures energy efficiency performance at plant-level for China's energy sector. The energy sector is the largest energy user both in terms of total energy consumption and the share of energy cost in the total cost (at a 2-digit industry classification level). Moreover, the Chinese government has recognised that one way to manage the country's environmental challenges and heavy dependence on imported energy is for the energy sector to achieve greater efficiency.

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Most studies on measuring China's energy efficiency were conducted in the framework of the input-oriented Data Envelopment Analysis. This approach generally calculates the technical efficiency by shrinking all the input factors equally proportionally subject to the observed output still being producible. Thus, all the input factor efficiencies, including the energy efficiency, are measured as the technical efficiency. One drawback of this approach is the presumption of an identical input factor frontier for all input factors. The study of Shi et al. (2010) imposed a restriction to hold the non-energy input fixed while seeking the energy input frontier, which, although addressing the above-mentioned presumption somehow, essentially assumed that the energy and non-energy inputs are perfect substitutes. There has been a controversy regarding whether energy and capital are substitutes or complements in the literature. For example, Hudson and Jorgenson (1974), Berndt and Wood (1975), and Fuss (1977) found the two factors as complements, while Griffin and Gregory (1976) and Pindyck (1979) found them as substitutes.

Substitutions between production factors are generally price induced but can also result from other actions on the part of the producer. In the case of an energy input, a substitution away from it can show up as an improvement in energy efficiency in the sense that the output-energy ratio can increase. It is not impossible, albeit unlikely, that the ratio could rise amid a decline in the technical efficiency of energy utilisation. This paper aims to measure energy efficiency in such a way that an improvement (worsening) in energy efficiency is necessarily the result of an improvement (worsening) in the technical efficiency of energy utilisation which is normally determined by technological and managerial factors, and hence is deemed the true cause of energy efficiency. Since factor substitutions and changes in technical efficiency can take place simultaneously, there is a need to control for the substitution effect to evaluate energy efficiency.

Using the stochastic frontier analysis (SFA), the current study is able to address the above-mentioned methodological issues by measuring energy efficiency as the gap between the substitution-corrected actual and minimal feasible energy consumption. To control for the substitution effects amounts to correcting the effects of energy-related allocative inefficiencies on the energy efficiency measure. Substitution–correction can be achieved by adopting a counter-factual approach which involves simultaneously evaluating all factor use efficiencies against their respective would-be factor uses should there be an absence of allocative inefficiencies.

The data used in the study were collected from 150 plants from China's energy sector and cover the period 2000–2005 when the growth of total energy consumption had exceeded that of total output measured as the gross domestic product of the country. This period had also witnessed a significant growth of the dependence on imported oil and a big surge of oil prices. The efficiencies of three types of energy, namely, coal, electricity and other fuels (*ofs*), are estimated in conjunction with capital and labour efficiencies. The *ofs* mainly include natural gas and petroleum products. The analysis produces the estimates of plant and time specific energy efficiencies and a four-way decomposition analysis to evaluate the effects of returns to scale on the energy efficiencies.

The contributions of the paper to the literature are threefold. First, it provides a micro-level and industry specific energy efficiency analysis for China's energy sector which is a major energy consumer and is flagged by the government to improve energy efficiency. The literature shows that the level of energy efficiency varies significantly between industries and regions in China. Therefore, new industry and/or region specific studies enrich the general understanding of the performance of energy efficiency in the country. Second, the micro-level data enables comparisons of efficiency performances between coal mines, petroleum refineries and power plants in the country. Knowledge of the efficiency performances of the three types of energy producer is important for the design of China's industry specific energy policy. A surge in capital investment in the coal industry during the study period also lends itself to inquiries about changes in productivity and efficiency as consequences of the large scale capital expansion. Third, the present study addresses the effects on measuring energy efficiency of possible substitutions between energy and non-energy factors that are generally unobservable.

The plan of the paper is as follows. The following section presents a brief review of energy efficiency measurement in the literature. Section 3 provides a commentary on the macroeconomic characteristics of the energy sector in terms of price movements and output growths. Section 4 describes the analytical framework. Data description and model specification and estimation are given in Section 5. Section 6 presents discussions of empirical results with some concluding remarks contained in Section 7.

2. Previous studies on measurement of energy efficiency

In the literature, energy efficiency is commonly measured as the ratio of output to energy input, that is, output per unit of energy. The numerator and the denominator of the ratio are typically aggregates of outputs and energy inputs, respectively. Therefore, an increase in the ratio is interpreted as an improvement in energy efficiency. Such a ratio cannot, however, differentiate between substitution away from energy, which amounts to energy conservation, and an improvement in energy efficiency itself, since both can lead to an increase in the ratio. Substitution away from energy will take place when energy becomes more expensive relative to other production factors, such as, capital; while a more efficient utilisation of energy will result when there is an improvement in technical efficiency and/or a technological progress in energy utilisation. Substitution can also take place between different types of energy, which introduces energy quality issues into measurement of aggregate energy efficiency. Thus, there is a need to overcome the deficiency of using the ratio to measure energy efficiency.

While Allan, Hanley, McGregor, Swales, and Turner (2007) measure energy efficiency in the thermodynamic sense, that is, an improvement in energy efficiency is equivalent to an increase in the value of heat contents for the same amount of energy in natural units, most studies measure energy efficiency as the ratio of output of a process to energy input into the process (Patterson, 1996). For example, Farla, Cuelenaere, and Blok (1998) interpreted the inverse of energy intensity, measured as the ratio of physical energy consumption to output, as energy efficiency in The Netherlands. Their study attributed changes in such a ratio to changes in energy efficiency and structure, where "energy efficiency" was the inverse of energy intensity at the sector level. Koopmans and te Velde (2001) measure energy efficiency as energy conservation due to substitution of new and energy-saving capital for energy with a