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The economy-wide rebound effect from improved energy efficiency in Swedish industries–A general equilibrium analysis

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HIGHLIGHTS

- We model the rebound effect from efficiency improvements in industrial energy use.
- We examine different assumptions that are important to the size of the rebound effect.
- We find that rebound effects in the range of 40–70 per cent for the Swedish economy.
- We conclude that technological development will lead to energy conservation.
- We find that the rebound effect is lower if improvements in energy efficiency are costly.

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ABSTRACT

The objective of this paper is to analyse the rebound effect from increased efficiency in industrial energy use in Sweden. Energy efficiency improvements can have significant micro- and macroeconomic effects that hamper the positive effect on real energy savings. To assess the size of the overall rebound effect in the Swedish economy, we apply a computable general equilibrium model. The results show that the economy-wide rebound effect depends on a number of factors, e.g. the extent of the energy efficiency improvement, how the labour market is modelled as well as whether the increase in energy efficiency is combined with a cost or not. We find that the rebound effect following a five per cent increase in energy efficiency in the Swedish industry lies in the 40–70 per cent range. When energy efficiency is only improved in energy-intensive production, the rebound effect becomes even higher. These findings are in line with the results in the literature.

1. Introduction

1.1. Background

Energy efficiency has become a keyword in climate and energy policies. The term is often used synonymously with reduced energy use and is expected to lead to reduced environmental impacts and improved security of energy supply. However, it is not given that improved energy efficiency will always meet such expectations. Increased energy efficiency can stimulate new demand for energy that counteracts the energy-saving potential. This so-called rebound effect can partially or wholly offset, or in worst case even outweigh, the energy-saving effect of energy efficiency measures. The extreme outcome of increased energy use has been labelled the Jevons paradox (Jevons, 1865; Alcott, 2005), the Khazzoom/Brookes postulate (Brookes, 1979, 1990; Khazzoom, 1980; Saunders, 1992) and more recently 'backfire' (Saunders, 2000).

Despite that the rebound effect is generally accepted in the literature and is most relevant for evaluations of environmental and energy policies, it is seldom taken into account in policy analyses. There are several reasons for this. The rebound effect is by nature abstract and dynamic, and therefore difficult to measure. It has been evaluated using a variety of methods, at both micro- and macroeconomic level, with different time perspectives. The many approaches have contributed to a wide spread in the empirical estimates, which in turn have contributed to divergent conclusions about the size and relevance of the rebound effect (Greening et al., 2000; Sorrell, 2007; van den Bergh, 2011; Turner, 2013).

No consensus around a specific definition of the rebound effect has yet emerged. The rebound literature has previously focused on energy efficiency improvements in terms of less energy use per unit of output, but has recently advanced to consider behavioural

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changes and the indirect energy use embodied in re-spending decisions (Druckman et al., 2011; Freire-Gonzalez, 2011). In this study we focus on rebound effects from technological measures.

Attempts have been made to categorize different economic feedback effects in terms of rebound effects to structure the empirical evidence. The rebound effect can broadly be defined in terms of direct and indirect effects adding up to the overall rebound effect (Sorrell and Dimitropoulos, 2008). The direct rebound effect is evaluated within tight analytical frames and applies to the demand for individual energy services, e.g. car transports. The indirect rebound effect consists of a number of indirect effects that follow from increased energy efficiency. The indirect effects may be broadly categorised as: (i) income, output and substitution effects; (ii) general equilibrium effects in terms of long-run structural change following changes in relative prices and (iii) radical changes in the social structure relating to technological development, preferences and institutions (Greening et al., 2000). When the overall rebound effect concerns the whole economy (a region, a country or the global economy), it is called the economy-wide rebound effect.[1]

In this paper, we use a computable general equilibrium (CGE) model for the Swedish economy to evaluate the economy-wide rebound effect that follows from a five per cent increase in the efficiency of industrial energy use in Sweden. Any cost-effective improvement in energy efficiency will lower production costs and thereby enhance competitiveness, especially in energy-intensive industries. Improved efficiency will change relative prices and potentially affect consumption and production levels in the whole economy. By applying a CGE approach we hope to capture as much as possible of these dynamic effects.

We contribute to the literature by adding to the evidence on the magnitude of the rebound effect. Our results are relatable to studies for the UK as a whole and regionally for Scotland (Allan et al., 2007; Hanley et al., 2009). Differences and similarities in our results, compared to the results of these studies, are described in order to deepen the understanding of the mechanisms at work and the magnitude of the rebound effect. In addition we model a no-growth scenario where the improvement in energy efficiency is balanced by lower productivity in value added.

Sweden is an interesting economy to study as it is relatively energy intensive. Sweden is also a forerunner in climate and energy policies, e.g. a carbon tax was introduced in 1990 and a target for energy efficiency in 2008. In 1980 Sweden held a referendum concerning the future of the Swedish nuclear power and a majority voted for a gradual phase-out. Closing down electricity capacity has proven to be troublesome despite large investments in renewable energy and energy efficiency. In 2004 a programme for increased energy efficiency in energy-intensive industries (PFE) was introduced. Furthermore, the Swedish government recently increased its funding of energy-related research to enhance technological progress. These political decisions were mainly driven by environmental concerns and energy security. The success of these actions is partly dependent on the rebound effect.

1.2. Previous literature

A number of papers have explicitly discussed the rebound effect in general and provided overviews of the literature (Greening et al., 2000; Berkhout et al., 2000; Binswanger, 2001; Sorrell, 2007; Sorrell and Dimitropoulos, 2008; Sorrell et al., 2009; Herring and Sorrell, 2009; Madlener and Alcott, 2009; van den Bergh, 2011). In the present paper, we focus on the economy-wide rebound effect from increased efficiency in industrial energy use (see Dimitropoulos (2007) and Allan et al. (2009) for thorough discussions).

1.2.1. The economy-wide rebound effect

The overall rebound effect has been estimated using microeconometric models on household data that capture income and substitution effects among households (see e.g. Brännlund et al., 2007). Macroeconomic models, both econometric models (see e.g. Barker et al., 2009) and CGE models (see e.g. Allan et al., 2009), also capturing effects on the production side of the economy and structural change, have been used. The CGE approach is most common in analyses of the rebound effect of energy efficiency improvements in industries. As the CGE models differ in structure and assumptions, it is difficult to compare these studies and to draw any general conclusion about the size of the rebound effect (Allan et al., 2009).

Grepperud and Rasmussen (2004) use a CGE model for Norway to analyse the effects of doubling the energy productivity in six energy-intensive sectors. The study focuses on energy use in individual sectors. Increased energy efficiency results in backfire in the most energy-intensive sector ('manufacture of metals'). They conclude that high energy intensity in itself does not cause backfire; good substitution possibilities are also required. Backfire does not occur in the energy-intensive pulp and paper sector because the substitutability between energy and other input factors are assumed to be poor.[2] Vikström (2008) uses a CGE model for Sweden and studies a scenario where energy efficiency is improved by 15 per cent in the manufacturing industry and 12 per cent in the energy sector. The results show a rebound effect of approximately 60 per cent. As the model is calibrated to the year of 1957 and only simulates five years (to 1962), little can be said about the current state of the Swedish economy. Washida (2004) simulates the effects of a one per cent improvement in the end use of energy in both industries and households in Japan, and finds a rebound effect of 53 per cent.

Allan et al. (2007) apply a CGE model for the UK economy (UKENVI) to analyse a five per cent increase in energy efficiency in all sectors of production (including five energy sectors). They find a long-run rebound effect of 27 per cent for electricity and 31 per cent for other energy. They also unexpectedly find that the rebound effects are higher in the short run, 62 per cent for electricity and 55 per cent for other energy.

A crucial difference between the short and long-term is that some production factors, especially capital, are assumed to be rigid in the short term. It is therefore not possible for businesses to fully adjust to energy efficiency improvements in the short-term. Improvements in energy efficiency will increase the returns from investments in energy-intensive sectors relative to investments in other sectors. In the long term, resources will be redistributed to the benefit of energy-intensive sectors. Thus, it is reasonable to expect that the rebound effect is higher in the long term (Wei, 2007; Saunders, 2008).

Turner (2009) explains that the long-run result in Allan et al. (2007) is caused by a negative investment effect in the domestic energy sectors. Following the initial energy efficiency improvement demand for energy falls in the short run as the economy cannot fully take advantage of the productivity improvement. The fall in demand puts a downward pressure on energy prices which

[1] This typology is not complete. Turner (2013) offers a comprehensive review of categorisations and argues that it may be too early to settle on a specific typology since it is somewhat confusing (overlapping) and since all the mechanisms underlying the overall rebound effect may not yet be known. Recently focus has been given to rebound effects through long-run technological innovation and diffusion and the role played by changes in the productivity of non-energy inputs (van den Bergh, 2011; Saunders 2015).

[2] In their model, energy and capital are nested to an intermediate factor of production, which implies that energy cannot be directly substitued for labour.