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International spillover and rebound effects from increased energy efficiency in Germany

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ABSTRACT

The pollution/energy leakage literature raises the concern that policies implemented in one country, such as a carbon tax or tight energy restrictions, might simply result in the reallocation of energy use to other countries. This paper addresses these concerns in the context of policies to increase energy efficiency, rather than direct action to reduce energy use. Using a global CGE simulation model, we extend the analyses of 'economy-wide' rebound from the national focus of previous studies to incorporate international spill-over effects from trade in goods and services. Our focus is to investigate whether these effects have the potential to increase or reduce the overall (global) rebound of local energy efficiency improvements. In the case we consider, increased energy efficiency in German production generates changes in comparative advantage that produce negative leakage effects, thereby actually rendering global rebound less than national rebound.

1. Introduction

The pollution/energy leakage literature raises the concern that policies implemented in one country, such as a carbon tax or tight energy restrictions, might simply result in the reallocation of energy use to other countries (Babiker, 2005; Böhringer and Löschel, 2006; Löschel and Otto, 2009; Elliot et al., 2010). This paper addresses these concerns in the context of policies to increase energy efficiency, rather than direct action to reduce energy use. It focusses on measures of the rebound effect.

Improvements in energy efficiency are typically associated with smaller proportionate reductions in energy use. This shortfall is known as the rebound effect. Its primary cause is the fall in energy prices, as measured in efficiency units, which produce substitution and income effects. These tend to offset some of potential reductions in energy use generated through improvements in energy efficiency (Berkhout et al., 2000; Birol and Keppler, 2000; Brookes, 1990, 2000; Greening et al., 2000; Herring, 1999; Jevons, 1865; Saunders, 1992, 2000a,b; Schipper and Grubb, 2000; Van den Bergh, 2011). In order to fully identify rebound ideally a system-wide method should be adopted, with the most common approach being the use of multi-sector Computable General Equilibrium, CGE, models (Sorrell, 2007).

In this paper we investigate how the concept and treatment of economy-wide or 'macro-level' rebound can be extended to take into account these wider impacts that occur through international trade effects. Whilst Wei (2010) presents a theoretical analysis of 'global rebound' and there are a number of applied studies, including Barker et al. (2009), the potential spillover effects from energy efficiency improvements in one nation on energy use in other nations have generally been neglected (Madlener and Alcott, 2009; Sorrell, 2009; Turner, 2013; Van den Bergh, 2011). Our central aim is to test whether by ignoring changes in energy use in other countries we underestimate rebound effects.

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We therefore use a multi-region CGE world model, developed along the lines of the basic version of the WIOD CGE framework (Koesler and Pothen, 2013), to extend the spatial focus of the rebound literature.[1] The work involves simulating the impact on global energy use of increased energy efficiency in German industrial production. The specific aim is to identify the extent to which the measured rebound effects increase or fall when energy use outwith the country experiencing the initial efficiency improvement in included. This is an important knowledge gap, particularly given the global nature of energy-related climate change and the existence of supra-national policy targets, such as the EU 20-20-20 framework.

Section 2 derives the analytical expressions required to extend the rebound calculation to incorporate endogenous changes in energy use at extended spatial levels and considers the types of channel through which an efficiency improvement in energy used in production in one nation can spill-over to impact energy use in direct and indirect trade partners.[2] Section 3 provides an overview of the world CGE framework used and Section 4 outlines the simulation strategy. Sections 5 and 6 report results from two sets of simulations, both involving a 10% increase in energy efficiency in production in the German economy. In the Section 5, the energy efficiency improvement applies only to the Manufacturing sector. In Section 6, it applies to all production sectors. Figures are given for the change in key economic variables in Germany, the rest of the European Union (REU) and the rest of the world (ROW) and a number of rebound measures are calculated. Section 7 draws conclusions and recommendations for future research.

2. Extending the boundaries of the economy-wide rebound effect

In this paper we build on the economy-wide rebound specifications derived in Lecca et al. (2014). We consider the national and global general equilibrium rebound effect following an improvement in the efficiency with which energy is used first in one production sector and then across all production sectors in a single national economy.

2.1. Home economy effects

2.1.1. Energy efficiency improvements in a single sector

Own-sector rebound in the targeted sector *i*, (the sector receiving the efficiency improvement) is identified as R_i, and is reported in percentage terms. It implicitly incorporates general equilibrium feedback effects on sector *i*'s energy use, in addition to direct and indirect rebound effects. It is defined as:

$$R_i = \left[1 + \frac{\dot{E}_i}{\gamma}\right] 100, \quad (1)$$

where $\dot{E}_i$ is the change in energy use in sector *i* after all agents have adjusted their behaviour in consequence of the technical energy efficiency improvement,$\gamma>0$. Both the energy efficiency improvement,γ, and the change in energy use, $\dot{E}_i$, are given in percentage terms. If the percentage reduction in energy use equals the increase in productivity, so that $-\dot{E}_i = \gamma$, then $\mathrm{R_i}$ is zero and there is no own-sector rebound. However, if the proportionate reduction in energy use is less than the increase in efficiency, then rebound occurs.

The energy efficiency improvement impacts the own-sector energy use primarily through the following channels. First, there is substitution towards energy, measured in efficiency units, in production in the target sector. This reflects the fall in the price of energy used in that sector when that energy is measured in efficiency units. This means that the sector's proportionate fall in energy use per unit of output, now measured in natural units, is less than the efficiency improvement. The second channel is the increased competitiveness of the target sector. This is driven by the reduced costs associated with the fall in intermediate input use and generates increased demand for the output of the sector as product price falls. The increase in demand for the product is accompanied by an increase in the derived demand for the energy input. Both the substitution and competitiveness effects increase the rebound value.[3]

The first step in identifying the own-country economy-wide rebound effect is to consider the impact on total energy use in the aggregate production side of the economy (all $i = 1, \ldots, \mathrm{N}$ sectors), E_p. The own-country total production rebound formulation, R_p, is given as:

$$R_p = \left[1 + \frac{\dot{E}_p}{\alpha\gamma}\right] 100, \quad (2)$$

where α is the initial (base/reference year) share of sector *i*'s energy use in total energy use in production (across all $i = 1, \ldots, \mathrm{N}$ sectors) in the domestic economy. The term $\dot{E}_p/\alpha\gamma$ can be expressed as:

$$\frac{\dot{E}_p}{\alpha\gamma} = \frac{\Delta E_p}{\gamma E_i} = \frac{\Delta E_i + \Delta E_p^{-i}}{\gamma E_i} = \frac{\dot{E}_i}{\gamma} + \frac{\Delta E_p^{-i}}{\gamma E_i}, \quad (3)$$

where Δ represents absolute change and the $-i$ superscript indicates all production excluding sector *i*. Substituting Eq. (3) into Eq. (2) and using Eq. (1) gives:

$$R_p = R_i + \left[\frac{\Delta E_p^{-i}}{\gamma E_i}\right] 100. \quad (4)$$

Eq. (4) indicates that the total (own-country) rebound in productive energy use depends on the net increase in aggregate energy use across all other domestic production sectors. As argued already, we expect the output of the target sector to rise and output in the energy sector to fall (as long as there is no ‘backfire’, i.e. rebound greater than 100%). An important third channel determining rebound is the reduction in energy use operating through the energy sector supply chain. Energy production is energy intensive. A reduction in demand for energy in the target sector will further reduce the demand for energy in the production of energy itself. This third channel reduces the rebound value. The intermediate energy demands across other sectors, that are not the target sector or the energy sectors, will reflect changes in the composition of final demand and the relative energy intensities of expanding and contracting sectors.

Using a similar procedure as outlined in Eqs. (3) and (4), and detailed in Appendix A, the full economy-wide rebound effect in the domestic economy, R_d, can be expressed as:

$$R_d = R_p + \left[\frac{\Delta E_c}{\gamma E_i}\right] 100. \quad (5)$$

where the *c* subscript indicates ‘consumption’ (households). Eq. (5) implies that the total economy-wide rebound in the home country, R_d, will be larger (smaller) than rebound in the aggregate production sector, R_p, if there is a net increase (decrease) in energy use in household final consumption.

The changes in domestic energy used in household consumption in principle are driven by changes in product prices and household income. We expect real household income to rise as the result of the increase in energy efficiency, thereby increasing rebound. In the present

[1] This paper separately identifies all EU countries but treats the rest of the World (ROW) as a single aggregate entity. However, in the reported results the European Union is separated into Germany and the rest of the EU (REU) so that when we refer to regions, we mean aggregations of national states.

[2] Lecca et al. (2014) investigate the economy-wide impacts of increased efficiency in household energy use. These differ from the impacts generated by the improvements in productive energy use considered here.

[3] To reiterate, this is not direct rebound; rather it is the rebound calculated incorporating the change in energy use in sector *i* with all general equilibrium effects of the efficiency improvement taken into account.