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Analysis

The added value from a general equilibrium analysis of increased efficiency in household energy use

Patrizio Lecca [a], Peter G. McGregor [a], J. Kim Swales [a], Karen Turner [b,c,*]

[a] Fraser of Allander Institute, Department of Economics and Strathclyde International Public Policy Institute, University of Strathclyde, United Kingdom
[b] Centre for Energy, Resource and Environmental Studies, Heriot Watt University, United Kingdom
[c] Department of Accounting, Economics and Finance, School of Management and Languages, Heriot Watt University, United Kingdom

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ABSTRACT

This paper investigates the economic impact of a 5% improvement in the UK household energy efficiency, focussing specifically on total energy rebound effects. The impact is measured through simulations using models that have increasing degrees of endogeneity but are calibrated on a common data set, moving from a basic partial equilibrium approach to a fully specified general equilibrium treatment. The size of the rebound effect is shown to depend on changes in household income, aggregate economic activity and relative prices that can only be captured through a general equilibrium model.

1. Introduction

There has been extensive investigation of the economy-wide rebound effects resulting from energy efficiency improvements in production. This analysis often uses a computable general equilibrium (CGE) modelling approach (see Dimitropoulos, 2007; Sorrell, 2007; Turner, 2013 for a review). However, very few studies have attempted to measure the economy-wide impacts of energy efficiency improvements in the household sector. Following the work of Khazzoom (1980, 1987) there have been a number of partial equilibrium studies (Dubin et al., 1986; Frondel et al., 2008; Greene et al., 1999; Klein, 1985, 1987; Nadel, 1993; Schwartz and Taylor, 1995; West, 2004). Further, Greening et al. (2000) give a detailed and extensive summary of the extent of rebound on household consumption of different types of energy services. These studies assume that there are no changes in prices or nominal incomes following the efficiency improvement, and that the impacts are limited to the direct market for household energy use. This approach gives an extreme partial equilibrium figure, which is generally known as the direct rebound effect.

To our knowledge, Dufournaud et al. (1994) is the only study that investigates full general equilibrium economy-wide rebound effects from increased energy efficiency in the household sector. It examines the impacts of increasing efficiency in domestic wood stoves in Sudan. Druckman et al. (2011), Freire-Gonzalez (2011) and Thomas and Azevedo (2013a, 2013b) use a fixed price input–output model to consider indirect rebound effects resulting from household income freed up by energy efficiency improvements and spent on non-energy commodities. This work includes changes in energy use in production, as well as household consumption. However, we still treat this as a partial equilibrium approach as it fails to incorporate endogenous prices, incomes or factor supply effects.

The aim of the present paper is to identify the added value from using general equilibrium techniques to consider the economy-wide impacts of increased efficiency in household energy use. We take as an illustrative case the effect of a 5% improvement in the UK household energy efficiency. The subsequent impact on energy use is measured through simulations employing models that have increasing degrees of endogeneity but are all calibrated on a common data set. That is to say, we calculate rebound effects for models that progress from the

* Corresponding author at: Department of Accounting, Economics and Finance, School of Management and Languages, Heriot Watt University, United Kingdom.
E-mail address: K.Turner@hw.ac.uk (K. Turner).

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most basic partial equilibrium approach to a fully specified general equilibrium treatment.

2. Rebound Effects

We categorise an increase in household energy efficiency as being a change in household “technology” that increases the energy services generated by each unit of physical energy consumed. An alternative way of expressing this is that the energy value in efficiency units has risen.[1] This implies that the original level of household utility can be achieved through the consumption of the original levels of other household goods and services, but with a lower consumption of energy.[2]

We define the rebound effect as a measure of the difference between the proportionate change in the actual energy use and the proportionate change in energy efficiency. This difference is primarily driven by the fact that, ceteris paribus, an increase in the efficiency in a particular energy use reduces the price of energy in that use, measured in efficiency units. This reduction then leads consumers to substitute energy, in efficiency units, for other goods and services implying that the proportionate reduction in energy use is typically less than the proportionate improvement in energy efficiency.[3] This is the rebound effect. Moreover, in principle, energy use can actually rise in these circumstances, if its use is sufficiently price sensitive. This is known as backfire (Khazzoom, 1980, 1987).

In the case under consideration here, for a proportionate improvement in household energy use of γ, rebound in the household consumption of energy, R_C, can be calculated as:

$$R_C = \left[1 + \frac{\dot{E}_C}{\gamma}\right] \cdot 100 \tag{1}$$

where $\dot{E}_C$ is the proportionate change in energy use in household consumption, which may be positive or negative.

We are also interested in the economy-wide rebound of household energy efficiency improvements: that is to say, the impact on energy use in the economy as a whole, both in consumption and production.[4] The total rebound formulation used in this case, R_T, is given as:

$$R_T = \left[1 + \frac{\dot{E}_T}{\alpha\gamma}\right] \cdot 100 \tag{2}$$

where α is the initial share of household energy consumption in total energy use. The term $\frac{\dot{E}_T}{\alpha\gamma}$ can be expressed as:

$$\frac{\dot{E}_T}{\alpha\gamma} = \frac{\Delta E_T}{\gamma E_C} = \frac{\Delta E_C + \Delta E_P}{\gamma E_C} = \frac{\dot{E}_C}{\gamma} + \frac{\Delta E_P}{\gamma E_C} \tag{3}$$

where Δ represents the absolute change and the P subscript indicates production. Substituting Eqs. (1) and (3) into Eq. (2) gives:

$$R_T = R_C + \frac{\Delta E_P}{\gamma E_C} \cdot 100. \tag{4}$$

This shows that the total rebound will be higher (lower) than the consumption rebound if the energy use in production increases (decreases) as a result of energy efficiency improvements in consumption.

3. Data and Elasticity of Substitution of Energy Use in Consumption

In this paper we identify the additional precision achieved through moving from a partial to a general equilibrium analysis of the rebound effects. We consider the specific case of energy efficiency improvements in household consumption.[5] We quantify the rebound effect through simulation using a given data set which provides common structural characteristics across all the models. Specifically we use a specially constructed the UK symmetric industry-by-industry Input–output (IO) table based on the published 2004 UK Supply and Use accounts.[6] Import data in Input–output format were provided by colleagues at the Stockholm Environment Institute. The Input–output accounts are aggregated to identify 21 economic activities (commodities/sectors). Table 1 gives the sectoral disaggregation, separately identifying the four energy sectors; coal, oil, gas and electricity.

Table 2 identifies the energy input requirement for each of the production sectors and the energy-output multiplier effects expressed in monetary terms. That is to say, for each sector we measure the direct and indirect increase in the value of output in energy industries generated by a unit increase in the final demand for that sector. The energy requirements are represented by the appropriate direct Input–output coefficients (the A matrix entries) whilst the energy-output multipliers are the corresponding entries in the Type I Leontief inverse, $[1\text{-}A]^{-1}$ inverse matrix. To calibrate the Computable General Equilibrium model, the conventional Input–output accounts are augmented with all other transfer payments to form the 2004 UK Social Accounting Matrix.[7] In all the analysis we use a single initial household consumption vector given in the UK 2004 Input–output accounts.

A key parameter that drives rebound analysis is the elasticity of substitution between aggregate energy and non-energy goods and services in the household's utility function. In each of the models we use, household utility, C, in any period is given by:

$$C = \left[\delta^E (\gamma E_C)^{\frac{\varepsilon-1}{\varepsilon}} + \left(1-\delta^E\right) NE_C^{\frac{\varepsilon-1}{\varepsilon}}\right]^{-\frac{\varepsilon}{\varepsilon-1}} \tag{5}$$

NE_C is the consumption of non-energy commodities, ε is the elasticity of substitution between energy and non-energy commodities in consumption and $\delta^E \in (0,1)$ is the share parameter. We estimate the value of the elasticity of substitution using the UK household consumption data from 1989 to 2008 employing the conventional generalized maximum entropy (GME) method (Golan et al., 1996).[8] Details of the estimation procedure are reported in Lecca et al. (2011, 2013b). The short- and long-run elasticities of substitution are estimated as 0.35 and 0.61 respectively. Our elasticity estimates are broadly in line with previous empirical evidence for the UK households (e.g. Baker and Blundell, 1991; Baker et al., 1989).[9]

[1] We discuss in Section 3 how such efficiency improvements might come about.

[2] We do not identify an improvement in household energy efficiency as simply a reduction in the direct energy intensity of consumption. For example, a fall in household energy use generated by an increase in the price of energy (through a carbon tax, for example) would not count as an improvement in household energy efficiency.

[3] The distinction between energy quantities and prices measured in natural and efficiency units is important in explaining how the rebound effect operates. However, in the present paper, unless we explicitly state otherwise, energy is being measured in natural units.

[4] Our interest here is limited to the rebound effect within the target economy, so that we abstract from potential spillover effects to other countries.

[5] We increase household efficiency in the use of all sources of energy: coal, oil, gas and electricity.

[6] See http://www.strath.ac.uk/fraser/research/2004ukindustry-byindustryanalyticalinput-outputtables/ for details.

[7] For more information on Input–output accounts and Social Accounting Matrices see Miller and Blair (2009).

[8] The value of the elasticity of substitution is likely to vary across types of energy services, such as personal transportation, residential space heating, etc. However, at this stage, for pedagogic reasons, we impose a common value across all household consumption energy uses.

[9] GME estimation is a widely used technique for generating parameter estimates for CGE models, though for comparative purposes OLS estimates are also reported in Lecca et al. (2013b).