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A new way to estimate the direct and indirect rebound effect and other rebound indicators

Jaume Freire-González

Department of Economics, Harvard University, Cambridge, MA 02138, United States

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ABSTRACT

Some progress has been done during the last years on the methods and provision of empirical evidence on the direct and indirect rebound effect. However, these methods are complex, and sometimes require some specific economic knowledge. The development of risk and vulnerability rebound indicators for economies can be a useful tool to help the research community, policy-makers and other practitioners to understand and tackle the rebound effect. This research shows a new analytical way to obtain the direct and indirect rebound effect from the direct rebound effect and the use of energy input-output coefficients, and proposes three risk and vulnerability rebound indicators to show the effects of energy efficiency improvements in households on overall energy consumption. An estimation of these indicators has been conducted for the EU-27 countries.

1. Introduction

The promotion of energy efficiency has been traditionally seen as a good and effective measure to reduce energy consumption and to fight global warming and climate change. However, there is an undesired effect, not always considered by analysts and policy-makers: the rebound effect [3–5,8,16,22–25,30,33,34]; etc. It is essentially, a secondary effect of energy efficiency actions or policies. It consists in an unexpected increase of energy consumption due to the reduction of the effective cost of providing an energy service in particular. Energy efficiency leads to this cost reduction. This effect was firstly identified by Jevons [21] and it is also known as the Jevons' Paradox.

Three types of rebound effect can be identified in literature [35]: direct rebound, affecting the energy consumption of the energy service affected by the energy efficiency improvement; indirect rebound effect, affecting other goods, services and areas; and economy-wide effects, going further, and affecting prices, quantities and producing global economic readjustments. A deep knowledge of the causes and consequences of energy efficiency measures on economic structures can prevent policy-makers from implementing inadequate measures, or at least can help to understand and control the rebound effect [14,18].

The present research focuses on the indirect rebound effects. A lot of progress has been done in this area during the last decade [2,10,12,13,15,17,20,36,37,40]. However, developed methods to estimate rebound effects and in general, the understanding of the effects of energy efficiency on energy consumption, remains still a complex issue for policy-makers and other analysis and practitioners from different disciplines. In many cases, they are not used to deal with such complex economic concepts, or modelling tools. The development of new indicators related to rebound effect can be useful, as it could simplify the understanding and increasing the evidence to carry out comparisons between sectors, countries and periods of time.

This research aims at identifying indicators of direct and indirect rebound effect for economies, as well as providing a new straightforward way to obtain the direct and indirect rebound effect from energy efficiency improvements in households. Section 2 describes the methodological context and provides some definitions from literature and a new analytical way to estimate the direct

E-mail addresses: jfreire@fas.harvard.edu, jaumefreire@hotmail.com.

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and indirect rebound effect in households. Section 3 provides new indicators to assess the rebound effect risk and vulnerability of economic regions. Section 4 shows the estimates of the described indicators at household level for all the first twenty-seven Member States of the European Union (EU-27). Finally, section 5 contains the main conclusions of the research.

2. Methodological framework

The methodological framework is based on a combination of environmental extended input-output analysis and re-spending modelling [11,12,17,20]. This is the starting point of the new developed way of obtaining the direct and indirect rebound effect and also for the other proposed indicators, as shown below.

2.1. Environmental extended input-output analysis

The energy Input-output model is a version of an environmental extended input-output model for energy [1,6,7,9,26,28,29,32].[1] The simplest formulation consists on mixing the traditional production Leontief approach [27] with a vector of energy intensities:

$$x = (I - A)^{-1} f \tag{1}$$

$$e = Ex \tag{2}$$

where $(I - A)^{-1}$ is the inverse matrix of the Leontief production model, f is the final demand vector for economic sectors, e is a vector of direct energy consumption of different economic sectors, E is a matrix of energy intensities or direct use coefficients of energy and x is a vector of sectoral production. If equation (1) is inserted into equation (2):

$$e = E(I - A)^{-1} f \tag{3}$$

This equation turns changes in consumption patterns (f) into direct and indirect energy consumption (e) of the economic system, considering interindustry relationships.

Then, if we substitute f for xp in equation (3), we can determine the direct and indirect effect of different consumption patterns through:

$$e = E(I - A)^{-1} xp \tag{4}$$

where x are quantities of goods and services and p are prices. Moreover, from equation (4), we can define the backward linkage coefficients in the consumption of energy as F_j. Where α_{ij} are the elements of $(I - A)^{-1}$:

$$F_j = \sum_{i=1}^{n} E_i \alpha_{ij} \tag{5}$$

2.2. Re-spending modelling and budget equilibrium

The re-spending model turns monetary savings from energy efficiency improvements into consumption patterns or final demands for different goods and services. It basically reallocates saving to purchases on different economic sectors. It represents the link between the direct rebound effect and the indirect rebound effect [12,17,36,37]. Definitions below of rebound effect and households' budget equilibrium are the basis for the analysis included in this research.

A general definition of the rebound effect for energy efficiency improvements is:

$$RE = \frac{\textit{Calculated energy savings} - \textit{Real energy savings}}{\textit{Calculated energy savings}} = \frac{\Delta H - (\Delta H - \Delta P)}{\Delta H} = \frac{\Delta P}{\Delta H} \tag{6}$$

On the other hand, the households' budget equilibrium can be formulated as:

$$y = x_E p_E + \sum_{i=1}^{n} x_i p_i + s \tag{7}$$

where y is the households' income or the total budget, x_E is the amount of energy, p_E is the price of energy, x_i is the amount of the good or service i (different form energy supply), p_i is the price of the good or service i, and s are other monetary savings in households.[2]

2.3. New method to estimate the direct and indirect rebound effect

This section contains a generalization of the analysis in section 2, and develops a new analytical way to obtain the direct and indirect rebound effect in households from only two sources: the own price elasticity of the demand for energy and the energy input-output coefficients.

As shown in section 2.2, the energy intensity coefficients from equation (3), turn a unitary monetary increase of final demand in each sector into an increase of energy usage of the overall economic system. So, a different reallocation of households' budget —what actually a re-spending model does-, would change total energy consumption. It is quite intuitive to assume that movements of expenses to sectors with higher energy coefficients would increase the total energy consumption, while movements to sectors with lower energy coefficients would reduce the total energy consumption.

At this point, we start taking definitions of: new households' spending on goods and services different from energy supply (equation (8)); new households' spending on energy supply (equation (9)); and initially expected households' spending on the energy sector after an energy efficiency improvement (equation (10)) as[3]:

$$\sum_{i=1}^{n} x'_i p_i = y - \left[1 + (-\vartheta_{p_s} - 1)\frac{\Delta\varepsilon}{\varepsilon}\right] x_E p_E - s \tag{8}$$

$$x'_E p_E = \left[1 + (-\vartheta_{p_s} - 1)\frac{\Delta\varepsilon}{\varepsilon}\right] x_E p_E \tag{9}$$

$$x_{E\ ref} p_{E\ ref} = \left(1 - \frac{\Delta\varepsilon}{\varepsilon}\right) x_E p_E \tag{10}$$

Where ϑ_{p_s} is own price elasticity of the demand for energy; $x_{E\ ref} p_{E\ ref}$ corresponds to engineering calculations of the new energy consumption after an energy efficiency improvement and $\frac{\Delta\varepsilon}{\varepsilon}$ is the energy efficiency variation. Equation (9) defines the new

[1] Details on this approach can be found at [31].

[2] For analytical purposes, we have split up the economy into the energy sector (E), and the rest are gathered under the index (i). This does not mean this development is only valid for a two sector economy, but that the rest of the sectors have the same treatment.

[3] Freire-González [17] shows the developments to obtain these definitions.