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Economic structure and energy savings from energy efficiency in households

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ABSTRACT

When an energy efficiency improvement occurs at the household level, several mechanisms, grouped under the name of the rebound effect, increase the available income and consumption, increasing the total energy consumption of the economic structure. The present research analyses the links between energy efficiency improvements in households, consumption, and the economic structure in an input-output framework. We examine, from an empirical perspective, the relationship between energy efficiency improvements and the economic structure, and between the direct and the indirect rebound effect. The limits of the input-output methodology in assessing the direct and indirect rebound effect have been empirically tested with respect to efficiency improvements of electricity uses in households in Catalonia.

1. Introduction

Technological progress has traditionally been the favoured solution to the problem of the increasing use of resources by the economy (Kemp, 1994; von Weizsäcker, 1994; Hinterberger and Schmidt-Bleek, 1999; Lovins and Lovins, 2001; Grubler, 2003). The underlying rationale is that the development of more resource-efficient technologies makes it possible to sustain the same level of material welfare using less resources, because it improves the productivity of factors, resources, and processes. Although this is an irrefutable fact within a technical-engineering framework, there are doubts about its validity at other levels of analysis, such as the socio-economic level. Indeed, there is a body of literature that provides empirical evidence for the fact that, while efficiency improvements in resource use have been continuous since early capitalism, the global consumption of resources such as energy has not stopped growing (Herring, 1999; Ayres et al., 2003; Fouquet and Pearson, 2006).

The relation between new energy-saving technological developments and sustainable consumption can be addressed from different perspectives. One of them is to consider the effects of changes in consumption patterns and the consequent effects on resource consumption in the economy when an energy efficiency improvement causes a change in disposable income. For instance, the case of energy efficiency improvements in household appliances leading to reductions in the unitary costs of the provided energy services (e.g. cost per cloth load of a washing machine). Along these lines, some authors have considered the effects from the re-spending of the additional disposable income within the so-called rebound effect framework (Jalas, 2002; Carlsson-Kanyama et al., 2005; Cohen et al., 2005; Takase et al., 2005; Mizobuchi, 2008; Nässén and Holmberg, 2009; Druckman et al., 2010; Thomas, 2011; Saunders and Tsao, 2012; Thomas and Azevedo, 2013a; Thomas and Azevedo, 2013b; Chitnis et al., 2013; Yu et al., 2013; Font Vivanco et al., 2014).

The rebound effect can be defined as the reduction in the potential or engineering energy savings resulting from technological improvements in the efficiency of providing an energy service (Wigley, 1997). That is, the difference between the initial expected energy savings from an efficiency improvement and the final consumption of energy. The rebound effect has mainly been discussed with respect to energy uses and analysed from different scopes and economic levels (Lovins, 1977; Brookes, 1979; Khazzoom, 1980; Saunders, 1992; Greening et al., 2000; Sorrell, 2007; Freire-González, 2010; Wang et al., 2012).

Most of the literature on the rebound effect has been oriented towards obtaining new empirical evidence (Ruzzenenti and Basosi, 2008). Saunders (2008) conducted a theoretical analysis of how the choice of production functions can inadvertently pre-determine results. According to the author, the Leontief function exhibits zero rebound when there is an improvement in energy efficiency of productive sectors.

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The aim of this paper is to analyse from an empirical perspective how the configuration of the economic structure affects the magnitude of the indirect rebound effect derived from energy efficiency improvements in households in a Leontief's framework. This is done by demonstrating the importance of the direct rebound effect over the indirect rebound effect.[1] Then, extreme scenarios are empirically tested to set the structural limits of the direct plus indirect rebound effects for a specific economic structure specified through Leontief production functions. Specifically, these scenarios have been applied to the case of efficiency improvements of electricity uses in households in Catalonia. This research deepens our understanding of the relationship between energy-saving technological change and sustainable consumption through the use of energy input-output analysis and re-spending analysis.

The theoretical framework and empirical contribution of this research is aligned with previous work conducted by Druckman et al. (2010); Freire-González (2011), and Thomas and Azevedo (2013a, 2013b), and particularly with the framework developed by Freire-González (2011). Druckman et al. (2010) does a related analysis based on exogenous behavioural changes, but not endogenous changes in energy efficiency improvements in households. Thomas and Azevedo (2013a, 2013b) perform an interesting application of the two first methodologies applied to the US context.

The model is applied to Catalonia for the year 2005. This analysis derives from a deeper analysis of the direct and indirect rebound effect derived from Freire-González (2011). The structure of the paper is as follows: Section 2 contains a literature review, in order to contextualize the issue; Section 3 explains theoretical and methodological aspects related to final consumption in households and total energy consumption in the economy; Section 4 characterizes the re-spending model by setting extreme scenarios to establish boundaries to the total energy use from technological improvements; Section 5 shows the data and the results from the empirical simulations. Section 6 presents the main conclusions.

2. The Indirect Rebound Effect and the Economic Structure in the Literature

The effects on energy consumption from the introduction of new energy-saving technologies in households have mostly been addressed from a static and direct perspective. Many empirical studies have estimated the direct rebound effect, defined as the increase in the demand of an energy service after the initial cost reductions caused by an energy efficiency improvement (Herring, 1999; Nesbakken, 2001; Guertin et al., 2003; West, 2004; Frondel et al., 2007; Davis, 2007). However, fewer studies have analysed the indirect rebound effect from an empirical perspective (Chitnis et al., 2012), i.e. the income and substitution effects[2] on the overall consumption basket induced by changes in disposable income from an energy efficiency improvement. Indirect rebound effects are those microeconomic effects produced in the short- and middle-term from an energy efficiency improvement that the direct rebound effect does not take into account. Whereas the direct rebound effect represents the increase in the demand of the energy service that was subject to an energy efficiency improvement, the indirect rebound effect represents the increase in the energy consumption needed to satisfy the increased demand for other goods and services (Alfredsson, 2004; Druckman et al., 2010; Freire-González, 2011). The present research is framed in the context of the study of indirect rebound effects. Another perspective, which is outside the scope of this research, addresses rebound effects from a macroeconomic perspective, through which it is possible to study macroeconomic and long-term effects (e.g. market price and growth effects), which can be used to provide insights for policy-makers in relation to global and complex issues such as energy supply and climate change (Jevons, 1865; Brookes, 1979; Saunders, 1992; Jenkins et al., 2011).

An important distinction to be made in the context of indirect rebound effects relates to the scope adopted when accounting for energy use; that is, whether only direct or embodied (or, alternatively, life cycle) energy use should be considered. With regards to this issue, a number of studies have estimated the energy content of the measures that lead to improved energy efficiency, mainly for domestic uses (Kaufmann and Azary-Lee, 1990; Feist, 1996; Winther and Hestnes, 1999; Casals, 2006; Royal Commission on Environmental Pollution, 2007; Sartori and Hestnes, 2007; Chitnis et al., 2013; Cellura et al., 2013). This approach to the indirect rebound effect is thus specific for each energy service. Furthermore, some authors argue that the embodied energy of the additional goods and services consumed constitutes an additional component of the indirect effect, in the form of the so-called "embodied energy" effect (Sorrell, 2007; van den Bergh, 2011). However, such considerations have been challenged by some authors (Murray, 2013; Font Vivanco and van der Voet, 2014), who have argued that the amount of energy use in upstream and downstream processes is the result of technological aspects rather than behavioural responses. Consequently, it is not appropriate to further decompose the indirect effect when an embodied or life cycle scope is adopted. Estimates of the embodied energy content of specific as well as general categories of goods and services can be obtained by means of environmentally-extended input-output analysis (EEIOA), life cycle assessment (LCA), or combinations of both in the form of hybrid LCA (Chapman, 1974; Herendeen and Tanaka, 1976; Kok et al., 2006; Joshi, 1999; Suh and Huppes, 2005).

In several studies, the empirical evidence of the rebound effect in the macroeconomic context was focused on the income effect caused by the introduction of efficiency improvements in energy services. This increase in disposable income stimulates consumption and associated energy demand. Some authors have used this interpretation, including Jalas (2002); Carlsson-Kanyama et al. (2005); Cohen et al. (2005); Takase et al. (2005); Druckman et al. (2010), and Freire-González (2011). Druckman et al. (2010) relate the changes in consumption patterns in households to the rebound effect. Using a quasi-multi-regional EEIOA model for the UK economy, they simulated the effects on greenhouse gas emissions from changing consumption patterns of households due to certain voluntary energy saving measures. Specifically, they estimated the *re-spending* effect of these actions. They found an indirect rebound effect of between 12% and 512%, with a most likely estimation of 34%, depending on the re-spending sectors. Another study for the UK (Chitnis et al., 2013), using a similar methodology, estimates the combined direct and indirect rebound effects from seven measures that improve the energy efficiency of UK dwellings in terms of greenhouse gases (GHG). Moreover, Thomas and Azevedo (2013a, 2013b) analyse the direct and indirect rebound effects for US households, also using an EEIOA approach. They obtained a rebound of 5–15% for primary energy and CO_2 emissions, assuming a 10% direct rebound effect. They also obtained an indirect rebound effect of 30–40% for NO_x and SO_2 emissions due to the increased efficiency in providing natural gas services.

Several authors have claimed that the indirect rebound effect caused by energy efficiency improvements is relatively small (Lovins et al., 1988; Greening and Greene, 1998; Schipper and Grubb, 2000; Dimitropoulos, 2007), owing to direct energy consumption making up a small part of total household expenditure. Adding to this, Greening and Greene (1998) argue that, for the vast majority of goods and services, the available data from input-output tables suggest that energy expenditure would be less than 15% of the total on average. However, other authors (Murray, 2013; Sorrell, 2007) have pointed out that the consideration of the embodied energy of products can notably increase indirect rebound effect estimates. Furthermore, Font Vivanco and van der Voet (2014) describe systematically larger rebound estimates from those studies applying a life cycle perspective.

[1] For definitions see Section **2**.

[2] The income effect relates to the change in the demand for a product (good or service) due to a change in the consumers' real income, while the substitution effect describes the change in demand due to a change in the relative price (relative to other products), controlling for the change in real income.