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The influence of energy efficiency on other natural resources use: An input-output perspective

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ABSTRACT

Energy efficiency improvements reduce the costs of energy services, and under some circumstances, increase the available income. This generates an additional increase of consumption of goods and services that need additional energy to be produced, distributed and consumed. This effect is known as the indirect rebound effect in the literature. However, beyond this additional increase of global energy consumption, there is also a variation of the use of other natural resources due to the same mechanism. This effect, which we label as direct and indirect cross rebound effect, is generally not considered by academia nor policy-making when designing and implementing energy policies. This research conceptualizes this effect, develops a methodology for its estimation and provides estimates for the Spanish economy. Results show that an energy efficiency in households could increase the use of minerals and water, while reducing the use of energy, fossil fuels and metal ores in Spain. These reductions, however, are lower than the expected ones from an input-output perspective, leading to positive direct and indirect cross rebound effects: between 64.6% and 74.7% for energy (equivalent to direct and indirect rebound effect); 48%–63% for fossil fuels. 84%–89% for metal ores; backfire for non-metallic minerals (147%–134%) and extreme backfire for water (1191%–1628%).

1. Introduction

1.1. Background and motivation

Energy efficiency improvements are often promoted to reduce energy consumption from different economic agents, such as households, industries and governments. Such improvements are applied to various areas, such as lighting, heating, cooling, industrial processes, and other areas that require energy. It is one of the most widespread policies to deal with energy dependency and environmental problems in most countries (IEA, 2015). Increasing concerns on climate change have also fostered these policies in order to reduce global carbon emissions and tackle global warming.

There is, however, a known controversy among energy economists. Energy efficiency improvements can be totally or partially offset by the so-called rebound effect. This effect has been widely studied for energy uses (Brookes, 1979; Khazzoom, 1980; Saunders, 1992; Greening et al., 2000; Sorrell, 2007; Freire-González, 2010). The intuition behind this effect is that an increase in the efficiency of using a given resource (e.g. energy) reduces the unitary cost of the service it provides (e.g. heating), from which follows an increase in its demand and the consequent offsetting of some or all of the initial expected savings.[2] This is generally known as the direct rebound effect (Greening et al., 2000). However, additional effects arise from an energy efficiency improvement, as there is also an increase of the available income that can lead to additional final demand for other products and services. This may in turn require such resource during their life cycle (from extraction to final disposal). This is commonly known as the indirect rebound effect (Greening et al., 2000).[3] Both effects have been extensively analysed for energy uses, but less for other natural resources (Font Vivanco and van der Voet, 2014). This is due to several reasons:

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[2] In this context, Becker's (1965) household production framework is useful to understand the demand of services provided by resources like energy.

[3] Literature also identifies economy-wide effects: they imply changes in prices, supplies and demands through the overall economic system. Increases in the overall economic productivity are usually also included in this typology, although they have other implications.

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the energy crisis in the 1970s and its importance in economic systems; the importance of energy in GHG emissions and global warming; energy dependence and geostrategic reasons, etc. A key question is thus how energy efficiency and its associated rebound effects affects the global use of natural resources other than energy. A better understanding of this question can help to anticipate unforeseen consequences, identify trade-offs and co-benefits and find optimal solutions between environmental problems.

Empirical evidence shows that the indirect rebound effect is a key driver of the overall rebound effect in many cases (Chitnis et al., 2013, 2014; Font Vivanco et al., 2014; Zhang et al., 2017a, b), and consequently an important body of research has focused on its study (Druckman et al., 2011; Sorrell, 2007). Research on the indirect rebound effect shows that energy efficiency improvements generally lead to monetary savings that can be re-spent on other goods and services, in turn increasing the overall energy consumption (Druckman et al., 2011; Freire-González, 2011; Thomas and Azevedo, 2013a, 2013b; Chitnis et al., 2014; Freire-González et al., 2017). In some cases, the indirect effect can even play a major role in superseding any energy savings (Druckman et al., 2011; Font Vivanco et al., 2015; Zhang et al., 2017a, b), a case commonly known as 'backfire effect' (Saunders, 2000). Some authors argue that, because goods and services are associated with multiple environmental pressures during their life cycle, such as waste and various air emissions, the indirect rebound effect can be expressed through various metrics (Alfredsson, 2004; Font Vivanco et al., 2014; Takase et al., 2005; Thiesen et al., 2008). Such a broader interpretation has sometimes been framed within the 'environmental rebound effect' (ERE) concept, which generalises the traditional energy rebound effect to encompass efficiency changes and indicators of interest that go beyond energy and energy-related emissions to a wide range of environmental issues (Font Vivanco et al., 2016; Goedkoop et al., 1999; Murray, 2013). Furthermore, the ERE approach has also incorporated other key characteristics from environmental-economic models, especially life cycle assessment and environmentally-extended input-output analysis. Specifically, the life cycle perspective, the high technology detail, and the use of environmental impact indicators (e.g. impact on ecosystems) (Weidema et al., 2008). Nevertheless, the study of rebound effects in the context of multiple environmental pressures, defined here as 'cross rebound effects', is in its infancy, with only a handful of empirical estimates available. Further research can provide a better understanding on the underlying reasons and the implications of such combined effects, including trade-offs, cobenefits and the possibility of backfire.

1.2. Objectives and structure of the paper

This research aims at developing a methodological framework that generalises the method to obtain the direct and indirect rebound effect of energy efficiency improvements in final demand uses, not only to energy consumption, but also to other natural resources. To this end, we develop the concept of the direct and indirect cross rebound effect, and apply it to estimate the impact of energy efficiency on the use of different natural resources in Spain. Specifically: energy, fossil fuels, metal ores, non-metallic minerals and water. This method allows to assess the increase/decrease in the global use of other natural resources following an energy efficiency variation in final demand uses. The direct and indirect cross rebound effect is an indicator analogous to the direct and indirect rebound effect that provides information on the overall effect.

Section 2 describes the proposed methodology to assess the direct and indirect cross rebound effect at the household (or final demand) level. Section 3 describes the data for the case study. Section 4 provides estimates of the direct and indirect cross rebound effects and a discussion of the results, and Section 5 shows the most relevant conclusions of the study.

2. Methods and models

The methodology described in this section is inspired by different academic backgrounds, but mostly from the direct and indirect rebound literature for energy efficiency. Some adaptations, however, are needed for its generalisation to other natural resources. Given that an improvement in energy efficiency has effects on the size and allocation of the final consumption, it has effects not only on indirect energy usage, but also on the indirect use of other resources. This consideration looks intuitive from a life cycle assessment perspective, where each unit of final consumption is associated with resource use over all its life cycle, including the extraction, production, use and waste management stages. So, how does the indirect rebound effect from an energy efficiency improvement affect the use of other natural resources beyond energy? To address this question, it is necessary a broad perspective and a thorough analysis of the indirect effects of energy efficiency improvements.

Particularly, Freire-González (2011) developed a framework for direct and indirect energy use from energy efficiency improvements in households (and other final demand uses) that can be adapted and generalized for other natural resources. Following this framework, three different steps are combined in this research, each using different methods. First, the use of econometrics and energy demand models to obtain the direct rebound effect from price-elasticity of demand for energy; second, the use of a respending model to allocate households' monetary savings from energy efficiency to other goods and services, considering households' budgets, and according to different scenarios; and third, an estimation of the direct plus indirect use of other natural resources from the new consumption pattern through the use of an environmental extended input-output framework (Miller and Blair, 2009).[4]

2.1. Direct energy rebound effect

The direct rebound effect for energy uses is the most analysed issue in both the theoretical and empirical rebound literature. There are well-established standard methods to obtain the direct rebound effect form energy services, and empirical evidence is sound (Sorrell, 2007). The most common way to estimate the direct rebound effect is through the use of elasticities of demand. The direct rebound effect can be defined as (Khazzoom, 1980; Berkhout et al., 2000; Dimitropoulos and Sorrell, 2006; Sorrell, 2007):

$$\vartheta_\varepsilon(x_E) = \vartheta_\varepsilon(S_E) - 1 \quad (1)$$

where $\vartheta_\varepsilon(x_E)$ is the efficiency elasticity of the demand for energy and $\vartheta_\varepsilon(S_E)$ is energy efficiency elasticity of the demand for useful work for an energy service. When the energy efficiency elasticity of the demand for useful work for an energy service is equal to zero, there is no direct rebound effect. When $\vartheta_\varepsilon(S_E) > 0$, so $|\vartheta_\varepsilon(x_E)| < 1$ there is a positive direct rebound effect. Finally, when $\vartheta_\varepsilon(S_E) > 1$, so the demand is elastic, would produce "backfire" (Saunders, 1992).

However, under certain assumptions, the rebound effect can also be obtained from the own price-elasticity of the demand for energy. Under this approach, the following equation can be

[4] Recent studies related to the use of input-output analysis to account for embodied energy and other natural resources are: Alcántara et al. (2017), Zhang et al. (2017a, b), Xia et al. (2017) and Wijayasundara et al. (2017).