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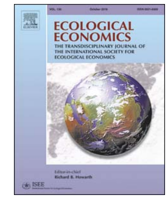

Analysis

Turn It Up and Open the Window: On the Rebound Effects in Residential Heating☆

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ABSTRACT

This paper investigates how households respond to efficiency improvements of their heating system. The analysis is based on the stated preference approach with an innovative choice experiment. The design includes questions to quantify both the direct and indirect rebounds. A series of easy discrete possible changes have been suggested to prime the respondents for deciding on potential actions impacting their heating service demand. Responses to these qualitative choices are moreover used to cross-validate the quantitative results. Overall, we find relatively low direct rebound effects. However, after accounting for the indirect rebound calculated using energy embodied in goods and services purchased by re-spending initial savings, we estimate an average total rebound of about one third. The econometric analysis points to substantial variations across individuals that are partly explained by observed characteristics. The results are consistent with the conjunction that heating is a basic need which calls for little rebound in high-income groups.

1. Introduction

Energy efficiency is often considered as the "invisible fuel" of the energy transition.[1] In Switzerland, like in many other industrialized countries, large efficiency gains remain feasible in buildings and heating systems. According to SFOE (2016), 37% of Switzerland's final energy consumption is attributable to heating and warm water, promising an important potential for energy savings. Yet, setting ambitious efficiency standards might not be sufficient to achieve the targeted energy conservation level, because a significant part of the expected energy savings could be lost due to behavioural adaptations known as rebound effects.

In this article, we investigate how households adjust heating usage and re-spend potential savings following an efficiency improvement of their heating system. The heating adjustment corresponds to a direct rebound (Sorrell and Dimitropoulos, 2008), whereas the re-spending leads to an indirect rebound. Our experimental design allows a simultaneous observation of both effects.

As a first in its kind, this paper relies on the contingent behaviour method, a type of stated preference approach. Respondents were presented with an exogenous efficiency improvement in their heating system, and were requested to use a sliding bar to represent their change of heating usage in reference to their current heating level. In addition to scripts describing the scenarios, potential behavioural reactions were suggested to prime respondents and cross-validate the results. A subsequent choice task was designed to identify the re-spending preferences for the remaining net savings, and hence the indirect rebound. This design constitutes the first attempt to identify underlying mechanisms of the rebound in heating, which could be due to an increase in temperature, but also to other reactions such as further airing or expansion of heating usage on space and time dimensions. Furthermore, this paper is among the few that seek to explain heterogeneity of rebound responses among individuals, in particular with regard to socio-economic variables, environmental concerns, and energy intensity usage.

Another important feature of this study is our particular effort in identifying respondents who have genuinely negligible or zero direct rebound. While this behaviour is not explicable for a utility-maximizing

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[1] See for instance *The Economist* (15th January 2015): "Energy efficiency: The invisible fuel".

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person with unlimited substitution, the outcome of our survey indicates that zero-rebound phenomenon deserves more attention. The wide range of rebound estimations observed in the empirical literature and the focus on average estimates may have hidden no-rebound individuals. In fact, we observe that a substantial share of respondents did not feel any appeal in increasing their heating usage only because it becomes cheaper. This observation points to hierarchical preferences (see e.g., Drakopoulos, 1994): Once a given level of thermal comfort is reached, efficiency improvements would not lead to more usage.

While recognizing that stated preference data face potential shortcomings, we contend that this approach deserves special attention in the rebound context. In our view, a choice experiment presents three important advantages over revealed data. First, the experiment design allows to eliminate the potential endogeneity bias encountered in the analysis of revealed data. Correcting for such selection bias would require valid instruments that are not readily available. In our experiment, efficiency improvements are randomly and exogenously assigned, hence preventing the possibility that intensive energy users systematically opt for higher efficiency. Second, stated data allow a better identification and validation strategy for zero-rebound individuals. Finally, the stated preference approach overcomes an important challenge in analysing the indirect rebound: In revealed data, it is practically impossible to link savings arising from a particular efficiency investment to a change in individual consumption pattern. In general, such savings become available over time in conjunction with a variety of other likely changes in income and savings. Identifying various rebound effects for the same individual would therefore require a prohibitively large amount of information. On the other hand, the experiment allows respondents to report their re-spending plan in a hypothetical context.

In our empirical analysis, we obtain an average direct rebound of 12% and an average indirect rebound of 24%. Combining both rebounds leads to a total micro-level rebound of around 33%. Moreover, our results indicate a strong heterogeneity among households, both for direct and indirect rebound effects, with about one third of the households displaying no direct rebound. Income is the main driver explaining the zero-rebound, showing that heating, as a basic need, calls for little rebound in high-income groups and those with a sufficient level of thermal comfort.

Policy makers in charge of the energy transition rely primarily on energy efficiency improvements to reach their targets of energy conservation, and in turn mitigate CO_2 emissions. Reliable estimations of direct and indirect rebound effects in the residential sector, as well as an overview of variations in households' responses to efficiency improvements, are therefore of crucial importance. The proposed analysis of the determinants of rebound responses is also relevant from a policy point of view, since it makes it possible to design customized measures targeted to specific population segments.

The remainder of the article is structured as follows. In Section 2, we provide an overview on how the rebound effects are defined and measured in the literature and in our experiment. Section 3 presents our survey and the data collected, while Section 4 reports our empirical estimations of the direct and indirect rebound effects. Section 5 investigates the determinants of rebound effects, relying on variations across households. Conclusions and policy implications are discussed in Section 6.

2. Rebound Effects in Residential Heating

Rebound effects (direct or indirect) can be measured through the difference, following an efficiency improvement, between potential and actual energy savings (e.g., Azevedo, 2014):

$$\text{Rebound effect} = 1 - \frac{\text{Actual energy savings (AES)}}{\text{Potential energy savings (PES)}} \tag{1}$$

The direct rebound is more precisely described as an increase in the consumption of an energy service following a decrease in the effective price of that service caused by an efficiency improvement (Sorrell and Dimitropoulos, 2008).

Energy efficiency is defined as $\varepsilon = \frac{S}{E}$, where E represents energy input and S energy services (or useful work). In our study, S represents the services provided by heating, and we emphasize that S is not only the indoor temperature, but it also encompasses several additional dimensions of thermal comfort such as airing frequency or whether all rooms are heated or not. The direct rebound can then be defined as the elasticity of the demand for energy services (S) with respect to efficiency (ε):[2]

$$\eta_\varepsilon(S) = \frac{\partial S}{\partial \varepsilon}\cdot\frac{\varepsilon}{S} \approx \frac{\Delta S}{\Delta \varepsilon}\cdot\frac{\varepsilon}{S} \tag{2}$$

For data-driven reasons, however, this definition is seldom used in empirical studies, and authors usually rely on alternative definitions such as the elasticity of service demand with respect to energy price. The latter is commonly used to approximate the direct rebound in the context of residential heating (Madlener and Hauertmann, 2011; Haas and Biermayr, 2000). Yet, strong assumptions have then to be invoked: people have to react symmetrically to a change in price and to a change in efficiency, a hypothesis rejected by Greene (2012) in the context of private mobility. Chan and Gillingham (2015) moreover demonstrate that fuel price elasticity is not equivalent to the rebound effect when multiple fuels can be used to provide a single energy service, which is the case for heating.

Some studies rely on engineering calculations to estimate potential energy savings. For instance, Aydin et al. (2014) study a large number of households in the Netherlands, comparing energy labels of dwellings with their actual energy consumption. They find a direct rebound of 28% for owners and 42% for tenants. This identification strategy has sometimes been criticised, mostly because it relies on engineering predictions that often over-estimate potential energy savings of efficiency improvements. As an example, Fowlie et al. (2015) study 30,000 households participating in an energy efficiency program in the US. They find that savings projected by engineers are roughly 2.5 times higher than actual savings. Attributing all this discrepancy to engineering over-estimation of savings, they conclude that there is no evidence of a direct rebound. One drawback is however that their definition of rebound effect is very narrow, considering only indoor temperature changes. In this article, we argue that the direct rebound is not only due to higher temperatures, but also to other heating-related behavioural adaptations. For instance, in their study of Danish households who installed a heat pump, Gram-Hanssen et al. (2012) observe various possible adaptations in addition to a temperature increase, such as extended heating areas and a longer heating season.

The literature provides a wide range of rebound estimates, suggesting that a variety of factors could characterize individual rebound behaviours. For residential space heating, Sorrell et al. (2009) review the literature and collect estimates of the direct rebound ranging from 10 to 58% in the short run, and from 1.4 to 60% in the long run. They propose a mean value of 20%. Nadel (2012) suggests a plausible range from 1 to 12% and questions studies claiming higher direct rebound because they are mostly based on price elasticity. More recently, Nadel (2016) summarises the findings of studies looking at both direct and indirect rebounds. For residential space heating, he observes a direct rebound around 10% and an indirect rebound around 10–20%, leading

[2] Recognizing that $\text{AES} = \frac{\Delta\varepsilon}{\varepsilon} - \frac{\Delta S}{S}$ and $\text{PES} = \frac{\Delta\varepsilon}{\varepsilon}$, we observe that definitions (1) and (2) are equivalent for the direct rebound:

$$\text{Direct RE} = 1 - \frac{\text{AES}}{\text{PES}} = 1 - \frac{\frac{\Delta\varepsilon}{\varepsilon} - \frac{\Delta S}{S}}{\frac{\Delta\varepsilon}{\varepsilon}} \approx \eta_\varepsilon(\text{S}).$$