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Rebound Effect in Energy Consumption

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1. Historical Background

The rebound effect as a phenomenon was first presented by the English economist William Stanley Jevons in his book 'The Coal Question' in 1865. He observed that while technological improvements resulted in more efficient utilisation of coal, it also led to higher consumption of coal in several industries during the 18th and 19th centuries. This effect, initially known as the 'Jevons Paradox', was revisited in the 1980s by J. Daniel Khazzoom and Leonard G. Brookes independently. They stressed that, at macroeconomic level and contrary to intuition, energy efficiency gains and reductions in energy intensity of output are linked to increases in energy consumption.

The validity of the Khazzoom-Brookes hypothesis was debated in the literature in the 1990s. In 1992, H.D. Saunders demonstrated that under certain assumptions the postulate is consistent with neoclassical growth theory. He identified two channels through which the rebound effect may occur. First, energy efficiency improvements result in energy appearing cheaper than other inputs, which implies that energy will substitute other inputs such as labour. Second, increases in economic growth boost energy consumption. Since then, despite the theoretical underpinnings, the scale and relevance of the rebound effect have remained contentious and spurred by the development of an extensive empirical literature.

2. What is Rebound Effect?

From a theoretical point of view, the rebound effect describes the potential energy savings that are offset when there are energy efficiency enhancements. In other words, rebound effects imply that energy efficiency improvements may lead to less than proportional reductions in energy consumption. Full potential energy savings are usually mechanically derived by assuming that demand for energy services remains unchanged after energy efficiency gains. However, energy efficiency enhancements implicitly imply a reduction in the marginal cost of energy, which may lead to an increase in the demand for that service and consequently to an increase in energy consumption. It is possible that this reaction may partially or fully offset the initial expected energy savings, often described as the 'rebound effect' or 'takeback'.

The literature on rebound effect has frequently attempted to pin down the definition and implications of the effect through distinguishing at least three types of them, namely, (i) direct, (ii) indirect and (iii) economy-wide rebound effects. The most apparent effect is the so-called direct rebound effect and implies that an improvement in energy efficiency for a particular energy service reduces the effective price of that service and provides incentives to increase its demand. Therefore, the response of consumers tends to offset the expected energy savings attributed to energy efficiency improvements. The indirect rebound effect arises from energy savings due to energy efficiency enhancement when they are reverted into demand for other goods and services that require energy for their provision. The economy-wide rebound effect relates to the reduction in the price of intermediate and final goods in the economy due to the decrease in real price of energy services. This results in adjustment of prices and quantities of goods and services consumed and create a bias towards consumption of the goods in the energy intensive sectors, which may then increase the overall energy consumption.

The above taxonomy of rebound effects is focused on end-use energy consumption. However, it is noteworthy that rebound effects may also arise from the productive side of the economy. The figure in the column on the right illustrates some examples of direct and indirect rebound effects both in the demand-side and supply-side of the economy.

Some researchers consider rebound effect as a natural adjustment to changing economic factors. In essence, this means that rebound effect can be considered as a reoptimisation process in response to price and income variations. From that perspective and using standard economic analysis, rebound effect represents a welfare improvement. However, in order to assess the net impact of rebound effect on overall economic welfare, the external costs generated by this phenomenon (e.g., through greenhouse gas emissions) should also be considered in the analysis.

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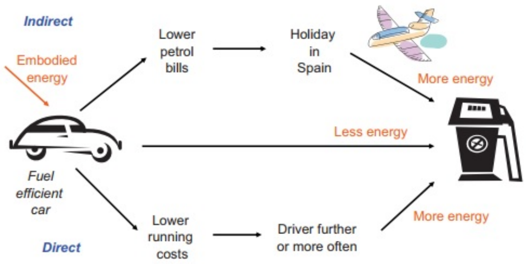

Fig. 1. Illustration of rebound effects for consumers.

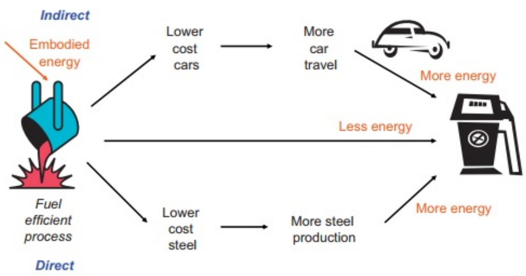

Fig. 2. Illustration of rebound effects for producers.

3. Empirical Evidence

The literature on rebound effect has focused both on the analytical definitions and empirical measurement using different approaches. Rebound effect can be depicted in terms of elasticity (η) of demand for energy services (or more precisely useful work, S) with respect to energy efficiency (ε). This elasticity, shown in Eq. 1, represents how demand for energy (services) changes when there is an increase in energy efficiency. The estimation of this type of elasticity is contentious because data on energy services and energy efficiency are often unavailable or can be flawed. In some cases, such as in road transport, energy services can be relatively easily measured (e.g., through vehicle-, passenger- or tonne-kilometre). However, independent estimates of fuel efficiency are difficult to use due to the lack of information or insufficient variation within the data.

$$\eta_{\varepsilon}(S) = \frac{\partial S}{\partial \varepsilon}\frac{\varepsilon}{S} \qquad (1)$$

Instead, own-price elasticities of demand for energy have frequently been econometrically estimated and used as indirect measures or proxies for rebound effect. A majority of studies assume that the response to changes in energy price is equal to the response in changes to energy efficiency. However, this approach can overestimate the rebound effect due to the endogeneity between energy prices and efficiency choice (e.g., through increasing load factor or purchasing more efficient vehicles in the case of transport), since these two factors are not independent of each other. Therefore, price-induced energy efficiency improvements should not be neglected when analysing rebound effects to avoid biased estimates.

There is a variety of estimated rebound effects in the literature not only because they use alternative definitions and methodological/empirical approaches, but also because they analyse the rebound effect for different energy commodities, countries or levels of data aggregation. Even in the case of specific sectors, such as the residential energy, a variety of rebound effects have been found. For instance, according to some studies, for residential lighting there is a narrow range of results for rebound effect from 5 to 12%. For other energy services there is a wider range of values: for space heating the range can be from 2 to 60%, for space cooling from 0 to 50%, for water heating from less than 10 to 40%, and for other consumer energy services from 0 to 49%.

Another example of the range of results obtained in the empirical research on rebound effect is the transport sector. Nevertheless, most rebound effects are estimated to be between 10 and 30%. Recent studies show that, in the case of road freight transport, rebound effects are estimated to be between 0 and 40% in the short run, while in the long run the values range between 10 and 85%. These results reveal that even when we restrict the rebound effect analysis to specific sectors or subsectors, there still remains an ample range of results arising from the diverse data, countries and approaches used, which has kept the debate on the rebound effect open.

4. Policy Relevance

In recent decades, large increases in demand for energy services have globally driven energy consumption. As a counterbalance, energy efficiency has become a key energy policy mechanism to tackle higher energy consumption and emissions, and countries and regions have adopted different targets and policies to achieve energy and environmental objectives. The main goals of these policies are to minimise the dependence on fossil fuels and mitigate local air pollution and GHG emissions. This has been particularly relevant for the energy-intensive sectors.

The development and deployment of more efficient technologies are, along with technology management, the main channel to achieve these environmental and energy objectives. However, as discussed, energy efficiency improvements can lead to changes in the demand for energy services that offset some of the expected energy savings. Consequently, forecasts of energy consumption reductions may be overstated.

As evidenced by the empirical literature, rebound effects can be a non-negligible issue. Therefore, ignoring them can imply an overestimation of the benefits coming from energy efficiency improvements. This can in turn lead to decisions such as the (over)allocation of public funds to ineffective environmental and energy policies. Policy makers need to take rebound effects into account for air quality, energy security and climate change policy reasons. A rebound effect different from zero implies that the expected proportional reductions in emissions from fuel efficiency improvements might not be achieved. Therefore, the policy goals to reach specific levels of emissions through fuel efficiency enhancements might need to be adjusted accordingly.

One of the envisaged scenarios for a decarbonised economy is one in which most energy services are provided by electricity. Full electrification could imply a reduction in GHG emissions and local pollutants without any decrease in the demand for energy services and avoiding concerns about rebound effects. However, this is likely to be affected by other considerations, such as capital costs, investment in infrastructures and management of the grid. Ultimately, the energy-mix will be paramount in this paradigm, since for this solution to become effective, electricity should be generated from low-carbon energy sources.

Despite the abundance of empirical studies, there is still a limited understanding of the rebound effect in specific sectors and countries. Further research on the rebound effect is still needed. The evolution and magnitude of the rebounds arising from higher energy efficiencies are relevant to assess the effectiveness of national and international energy and climate policies.

Empirical studies suggest that rebound effect can be of sufficient magnitude to be explicitly taken into account in policy design. These results are of direct relevance given that energy efficiency standards are among the main policy regulations to reduce environmental effects. If efficiency standards fail as pollution control tools, then measures such as fuel taxes, carbon taxes, feebates or cap and trade mechanisms could play a more prominent role in climate policies.

Finally, it is noteworthy that even when the 'relative' magnitude of the rebound effect is low, the environmental impact of foregone reductions from efficiency improvement can still be significant, due to the scale of the economic activity and the thresholds and marginal cost of the externalities.

References

This note summarises and relies on the content of our following research:

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