Guest editorial: Energy conservation, the rebound effect, and future energy and transport technologies: an introduction to energy conservation and the rebound effect

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1 The appeal of energy conservation

Facing a potentially substantial climate change, energy conservation – in the form of efficiency improvements in energy supply, conversion, and consumption – appears to be one of the most promising options of environmental protection. Reducing energy consumption not only mitigates possible future resource scarcities and, particularly, energy import pressures, which has been a major rationale for the most industrialised countries to impose conservation regulation. There is also hope that conservation of energy will diminish greenhouse gas emissions in particular and reduce environmental degradation in general – in some cases even without causing any losses in individual utility. Indeed, it is even promised that more efficient appliances will save both energy and money, see Lovins (1985), 'Saving gigabucks with negawatts'.

According to the claims of Lovins and his collaborators, conservation is either extremely cheap or even a 'free lunch' see Wirl (1997, p.193). Given all expected benefits, it is obvious why energy conservation is among the most appealing and accepted environmental strategies: Energy conservation is assumed to at once combat climate change, general environmental degradation, and resource scarcities, specifically energy dependencies, without causing substantial reductions in individual and social welfare, if at all.

Moreover, it is estimated that a substantial part of the emission reductions stipulated in the Kyoto protocol can be achieved by energy conservation. The 'Third Assessment Report' of the IPCC (2001, p.174) estimates that about half the technological potential for greenhouse gas emission reductions worldwide is also profitable. This so-called no-regret potential is gauged by the IPCC to range between 10% and 20% of global emissions in the year 2020. However, the potential energy savings resulting from energy-efficiency improvements frequently are overestimated – see, for example Wirl (1997, pp.24–26).

The reason for this overestimation is that behavioural responses evoked by efficiency improvements due to technological progress are often ignored – see, for instance, Binswanger (2001, p.120). Because specific cost – that is, the price per unit of an energy service, such as travelling miles for individual transport purposes – decreases with increased efficiency, the demand for this energy service usually rises. For example, irrespective of large investment costs incurred by the purchase of a new, more fuel-efficient car, it is most likely that the owner of the new car ceteris paribus will drive more in terms of passenger kilometres than before, since specific travelling costs are lower.

2 Microeconomic rebound effects

The example of the increased use of new and more fuel-efficient cars illustrates that the result of an x% increase in efficiency is not necessarily a decrease in energy use of x% but one that is frequently much less than x%. This phenomenon is commonly called the *rebound effect*, see e.g. Wirl (1997, p.25, 2000, p.93), for which Khazzoom (1980) has come up with a precise definition at the microeconomic level of households that raise the energy efficiency of a single energy service, such as space heating and individual conveyance.

The basic idea underlying Khazzoom's definition is that, ultimately, households are not interested in the amount of energy '*e*' that is necessary for a certain amount '*s*' of energy service, but in the amount of service itself. The higher the efficiency 'μ' of a given technology, which is defined by

$$\mu = \frac{s}{e},$$

the less energy '*e*' is required for a certain amount '*s*' of an energy service. Fuel-efficiency, for instance, is defined as passenger car miles per gallon of fuel input.

The behavioural response triggered by the reduction in the price of an energy service due to higher efficiency is called the direct rebound effect. It diminishes or even offsets energy savings and, hence, the benefits of efficiency gains, and is not restricted to the consumption of energy – it is a very general phenomenon. The direct rebound effect is, in fact, a special case of the Law of Demand, a basic economic principle that states that the consumption of goods usually increases with declining prices or perceived costs. For this reason, it is not surprising at all that rebound effects that are due to efficiency improvements occur in many contexts such as in response to water- and other resource-saving innovations and, specifically, time-saving technologies – see e.g. Binswanger (2001).

In addition to the direct rebound effect, Greening et al. (2000, p.390) identify secondary or *indirect rebound effects*: Given a fixed budget and constant prices of other commodities, the reduction in the cost of an energy service induces an income effect.

In other words, real income is actually higher, since there is more money left for all other goods and services. These commodities may also require energy. As a consequence, the total energy use might increase in those areas that are not directly affected by the improvement in energy efficiency. The size of the indirect rebound effect depends on the share of the consumer's expenditures on energy services. Since this share is typically small, indirect rebound effects are probably less significant.

Finally, general equilibrium effects resulting from successful radical energy efficiency innovations that substantially increase overall income potentials may cause dramatic changes in supply and demand in *all sectors* of society. Thus, in effect, path-breaking efficiency improvements, such as James Watt's famous steam engine – which was much more efficient than its predecessors – , may even lead to an overall increase in a society's energy consumption, rather than a substantial decrease, because these innovations stimulate economic growth. The next section presents a few examples of such general equilibrium effects, for which I would like to coin the notion *macroeconomic rebound effect*. These examples are based on path-breaking innovations that seem to be energy-saving, at first glance, but evoke adverse energy consumption effects. In sum, the economic literature mainly distinguishes between three different types of rebound effects: direct and indirect rebound effects, and economy-wide or general equilibrium effects – see Greening et al. (2000, p.390).

3 The macroeconomic rebound effect

Jevons, commonly honoured as the father of quantitative economics, is among the first authors who described the macroeconomic rebound effect by noting that conservation measures often produce the opposite of the intended effect (Jevons, 1865, p.140), original emphasis): "It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. *The very contrary is the truth*." Thus, "Khazzoom and Brookes credit [...] Jevons with the original observation that efficiency gains could increase consumption" (Saunders, 1992, p.132).

In the monograph "The Coal Question: Can Britain Survive?" Jevons (1865) illustrates his point, using the history of steam engines as an example. Compared to Watt's famous steam engine, the efficiency of its predecessors, the Savery and the Newcomen engines, were so low that they were hardly used. In total, the Savery engine "consumed (almost) no coal, because its rate of consumption was too high", (Jevons, 1865, p.143). It was only the Watt engine that initiated the world's industrialisation, causing coal use to skyrocket. This is but one of the most popular examples indicating that substantial energy-efficiency improvements at the microeconomic level of, here, individual machines often evoke adverse energy consumption effects at the macroeconomic level.

For such phenomena, Saunders (1992) coined the notion of the *Khazzoom-Brookes-postulate*: "Reductions in energy intensity of output that are not damaging to the economy are associated with increases, not decreases, in energy demand at the macroeconomic level" (Brookes, 1990, p.199). Ironically, it is the – certainly desirable – macroeconomic growth effect triggered by those radical innovations that improve energy efficiency at the microeconomic level that offsets these energy savings, which would reduce the overall energy consumption if there were no macroeconomic rebound effect.

Jevons (1865, p.143) also noted the example of the iron industry, in which

> "the reduction of the consumption of coal per ton of iron (produced), to less than one-third of its former amount, was followed in Scotland by a tenfold total consumption (increase) between the years 1830 and 1863." "Coal thus saved is (not) spared – it is only saved from one use to be employed in others, and the profits gained lead to extended employment in many new forms," Jevons (1865, p.155) concluded.

4 The national energy efficiency

National energy efficiency, defined as the gross domestic product (GDP) per unit of energy input, is one of the most popular indicators of energy conservation. However, an increase in this ratio is not necessarily accompanied by an overall decrease in energy consumption, a result that e.g. Schurr (1982, 1985) finds to be empirically true for a very long time in the USA. Unfortunately, the observation of increases in the value of this indicator that are not accompanied by a decrease of total energy consumption is often called a rebound effect, as well.

Yet, the coinciding increase of national energy efficiency and total energy consumption must not be confused with the phenomenon described by the macroeconomic rebound effect: If, for instance, there are no genuine energy-efficiency improvements, and, hence, there is simply no rebound effect, economic growth may cause higher levels of GDP and, in particular, energy consumption and national energy efficiency. If energy efficiency remains constant, and the indicator 'national energy efficiency' is raised by an increase in economic growth this measure falsely indicates an efficiency improvement. This example simply documents the fact that the indicator of national energy efficiency is an insufficient measure of energy efficiency – a fact that is also criticised by Herring (2004), among others.

A similar example of an increase in the level of both efficiency and absolute energy consumption, in which a genuine rebound effect is not present, refers to the increase of the US average of fuel efficiency of individual conveyance by automobiles, which was one of the most favoured means of mitigating adverse impacts of the OPEC price hikes in the 1970s. With fuel efficiency in individual transportation being defined as passenger car miles per gallon of fuel input, the increase of this fuel-efficiency indicator was one of the aims of the Energy Policy and Conservation Act. According to Inhaber (1997, p.65), this was the first explicit energy conservation law in the United States. While the US average of passenger car miles per gallon (mpg) amounted to 13.4 in 1974, the Corporate Average Fuel Economy (CAFE) standard for new cars implies an incremental increase in target levels, such as 18 mpg in 1977 and 26 mpg in 1981, with an ultimate standard of 27.5 mpg.

As a consequence, the US average reached a level of 21.4 mpg at the end of the 1990s – see EIA (2000, p.17), which was clearly far from both the ultimate target of 27.5 mpg and the intermediate target of 26 mpg in 1981, but was about 60% better than the 1974 value. If all other factors, such as national economic welfare and individual travelling behaviour, had remained unchanged, the US gasoline usage should have dropped by more than half. In fact, in spite of slight dips and rises, the level of total US gasoline supply remained roughly the same between 1973 and 2000, see e.g. Inhaber (1997, p.67). Clearly, this outcome is a consequence of the economic growth the

USA enjoyed within this period and the resulting income effect, which evoked both increases in the number of cars and individual passenger kilometres.

5 Summary and conclusion

Energy conservation is among the most appealing environmental strategies due to the expectation that conservation combats climate change, general environmental degradation, and resource scarcities, specifically energy dependencies, without causing substantial reductions in individual and social welfare. However, there are two shortcomings related to this promising strategy: While economic growth effects may offset possible energy savings, potential savings resulting from energy-efficiency improvements frequently seem to be overestimated – see, for example, Wirl (1997, pp.24–26): Because of behavioural responses evoked by efficiency improvements, the result of an x% increase in efficiency is not necessarily a decrease in energy use of x% but one that may be much less than x%. This is outcome is commonly called rebound effect.

Obviously, the magnitude of the rebound effect is the key to the absolute effectiveness of technological efficiency improvements and the relative effectiveness of energy-conservation programmes vs. energy-price or tax policies in reducing energy use. While there seems to be no question about the existence of the rebound effect, there is a controversy about its *magnitude*. Lovins (1988) maintains that the rebound effect is more likely to be an income, rather than an own-price effect, and is thus so insignificant that it can be safely neglected. On the other hand, Khazzoom (1987, 1989) argues that it might be so large as to nearly defeat the purpose of energy efficiency improvements.

Since the residential demand for energy services is typically weakly elastic, the rebound effect is rather moderate. Yet, it is not meaningless in most cases. In the context of transport-efficiency improvements, empirical studies on the rebound effect indicate that its magnitude lies within the range of 10–30%, see e.g. Binswanger (2001, p.124), while only a few analyses, such as Khazzoom (1986), display large rebound effects. In his econometric study on electrically heated homes in Sacramento, Khazzoom estimates that the long-run rebound effect of the residential demand for electricity is as large as 65%.

This debate is but one example showing that the evaluation of environmental programmes, such as energy-conservation programmes, is far from being an easy matter: "Most serious analysts recognise that it is quite difficult to accurately measure the energy savings resulting from utility conservation efforts" (Joskow and Marron, 1992, p.62). Certainly, this is the reason why empirical evidence on the genuine effects of energy conservation measures appears to be weak. It is thus the aim of this special issue on energy conservation to shed further light on energy conservation, the rebound effect, and future energy and transport technologies.

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