Some thoughts on rebound effects

Steve Sorrell, Sussex Energy Group, October 2011

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Below I offer some brief thoughts on rebound effects and some comments on the notion of ‘sufficiency’ as a response to rebound effects. The former is based upon the results of our review of evidence on rebound effects [1] and the latter from a recent paper on energy, economic growth and environmental sustainability [2].

Rebound effects, the UKERC assessment and Jevons Paradox

The potential ‘energy savings’ from improved energy efficiency are commonly estimated using engineering-economic models, but these neglect the impact of various behavioural responses to such improvements, such as increased demand for cheaper energy services. A variety of mechanisms contribute to such rebound effects, but their net effect is difficult to quantify and widely ignored. The UKERC assessment, published in 2007, sought to improve understanding of the nature and size of such effects and to examine whether they could be sufficiently large as to increase overall energy consumption (‘backfire’). The assessment was primarily based upon a review of existing research. Since the assessment was published, interest in this subject has grown, the volume of research has increased and understanding of the relevant issues has improved. However, rebound effects continue to be neglected by the majority of analysts and policymakers.

The assessment showed how quasi-experimental and econometric techniques have yielded relatively robust estimates of ‘direct’ rebound effects following improvements in the energy efficiency of household energy services in the OECD. These effects result from increased demand for the relevant energy services and typically erode up to 30% of potential energy savings before other indirect and economy-wide effects are accounted for. Direct rebound effects are likely to be greater in developing economies and also appear more significant in industry.

Quantification of the various indirect and economy-wide rebound effects is more difficult, but insights may be gained from energy-economic models of the macro-economy. The available studies relate solely to energy efficiency improvements by producers and show that the economy-wide rebound effect varies widely depending upon the nature of the energy efficiency improvement and the sector in which it takes place. All studies conducted to date estimate economy-wide effects in excess of 30% and several predict backfire. Moreover, these estimates do not take into account the amplifying effect of any associated improvements in the productivity of capital, labour or materials, although in practice these appear to be very common [3, 4]. Many, if not most improvements in energy efficiency are the byproduct of broader improvements in product and process technology and even dedicated investments to improve energy efficiency frequently have wider benefits [4, 5]. Since these additional cost savings will also contribute to additional energy consumption, this implies that the rebound effect from new technologies need not necessarily be small just because the share of energy in total costs is small—and that "win-win" opportunities will have the largest rebound effects [5].

Rebound effects need to be defined in relation to particular *measures* of energy efficiency (e.g., thermodynamic, physical, economic), to relevant *system boundaries* for both the measure of energy efficiency and the change in energy consumption (e.g., device, firm, sector, economy) and to a particular *time frame* [1]. Disputes over the size and importance of rebound effects result in part from different choices for each of these variables [1, 5]. Rebound effects may be expected to increase over time as markets, technology and behaviour adjusts. For climate policy, what matters is the long-term effect on global energy consumption from the adoption of new technologies.

Quantification of rebound effects is hampered by inadequate data, difficulties in establishing causal relationships, endogenous variables, trans-boundary effects and complex, long-term dynamics such as changing patterns of consumption. Since economy-wide effects are emergent phenomena [6] resulting from the complex interaction of multiple actors and mechanisms, studies of a subset of mechanisms within narrow spatial and temporal boundaries can provide only a partial picture. Generally, as the boundary and scope of analysis expands the estimated size of rebound effects increase. Energy efficiency improvements in the early stage of diffusion of 'general-purpose technologies' such as lighting, engines and motors could have rebound effects that exceed 100% (backfire). An early example of this was that steam engine.

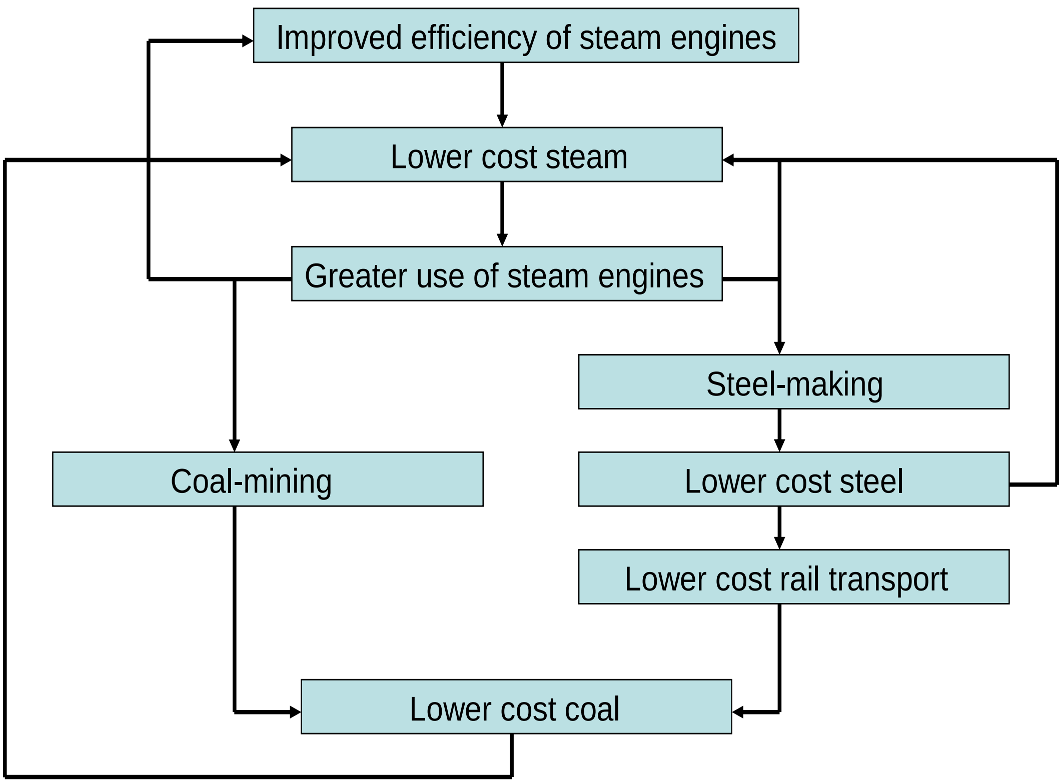
Jevons [7] argued that the early Savory steam engine used for pumping floodwater out of coal mines "…consumed no coal because it rate of consumption was too high". It was only with the subsequent technical and efficiency improvements by Watt and others that steam engines became widespread in coal mines, facilitating greater production of lower cost coal which in turn was used by comparable steam engines in a host of applications. One important application was to pump air into blast furnaces, thereby increasing the blast temperatures, reducing the quantity of coal needed to make iron and reducing the cost of iron. Lower cost iron, in turn, reduced the cost of steam engines, creating a positive feedback cycle. It also contributed to the development of railways, which lowered the cost of transporting coal and iron, thereby increasing demand for both.

Rosenberg [8] cited the comparable example of the Bessemer process for steel-making which: "…..was one of the most fuel saving innovations in the history of metallurgy [but] made it possible to employ steel in a wide variety of uses that were not feasible before Bessemer, bringing with it large increases in demand. As a result, although the process sharply reduced fuel requirements per unit of output, its ultimate effect was to increase....the demand for fuel" [8].

The low cost Bessemer steel initially found a large market in the production of steel rails, thereby facilitating the growth of the rail industry, and later in a much wider range of applications including automobiles. However, the mild steel produced by the Bessemer process is a different product to wrought iron and suitable for use in a much wider range of applications. Hence, for both steelmaking and steam engines, improvements in the energy efficiency of production processes were deeply and perhaps necessarily entwined with broader improvements in process and product technology.

Brookes [9] cited the example of US productivity growth during the 20th century. Energy prices were falling in real terms for much of this period with the result that energy substituted for other factors of production and increased aggregate energy intensity. But these substitution effects were more than outweighed by the technological improvements facilitated by the availability of high-quality energy sources which greatly improved the overall productivity of the US economy—for example, in transforming the sequence, layout and efficiency of manufacturing through the introduction of electric motors [10]. This meant that economic output increased much faster than energy consumption, owing to the greater productivity of capital and labour. The net result was to produce *falling* energy intensity (as measured by the energy/GDP ratio) alongside *rising* energy consumption—as Jevons' predicted. Polimeni [11] provides econometric evidence for this process for a number of countries and time periods.

Figure 1. Energy efficiency, positive feedbacks and economic growth in the 19th century.



These historical examples relate to energy efficiency improvements in the early stages of development of energy-intensive process technologies that are producing goods that have the potential for widespread use in multiple applications. The same consequences may not follow for energy efficiency improvements in mature and/or non-energy-intensive process technologies that are producing goods that have a relatively narrow range of applications, or for energy efficiency improvements in consumer technologies. Backfire seems more likely to occur over the long-term following improvements in the energy efficiency of "general-purpose technologies" such as steam turbines, lighting, motor vehicles and computers—particularly when these are used by producers and when the improvements occur at an early stage of development and diffusion [12]. These technologies have transformational effects, such as the growth of existing sectors, the emergence of new processes, products and services and changes in infrastructure, employment and consumer preferences. Moreover, such "general-purpose technologies" dominate overall energy consumption.

The UKERC assessment reviewed theory and evidence suggesting that there was relatively limited scope for substituting other inputs for energy. It also highlighted evidence showing how technical change has frequently acted to increase energy intensity, that weighting fuels by their relative 'quality' or economic productivity leads to different conclusions regarding the source and extent of decoupling and that improvements in the supply or productivity of high-quality energy inputs have synergistic and multiplicative impacts on the productivity of capital and labour [13]. All these observations point to energy playing a more important role in productivity improvements and economic growth than is conventionally assumed and can be used in support of the argument that rebound effects are large. But the assessment also highlighted numerous flaws in these arguments and evidence and concluded that a case for the universal applicability of 'Jevons Paradox' has not been made.

In sum, rebound effects appear to be larger than conventionally assumed will make energy efficiency improvements less effective in reducing overall energy consumption. This could limit the potential for decoupling carbon emissions from economic growth, since the contribution from improved energy efficiency will be less than expected—although by precisely how much remains unclear. In principle, increases in energy prices should reduce the magnitude of such effects by offsetting the cost reductions from improved energy efficiency. This leads to the policy recommendation of raising energy prices through either energy/carbon taxation or emissions trading schemes. Cap and trade schemes are particularly attractive since they focus directly upon the desired ends (e.g., reduced carbon emissions) rather than a potentially problematic means to achieve those ends (e.g., improved energy efficiency) [14].

'Sufficiency' as a response to rebound effects

The preferred strategy to achieve sustainability is *consuming more efficiently*, which implies reducing the environmental impacts associated with each good or service. But the extent to which this is successful will depend upon the size of any associated rebound effects. If these are significant, energy use may not be reduced as much as expected and in some circumstances could increase. Despite this, most OECD countries pay little attention to such possibilities and offer few options for mitigating the undesirable consequences.

A related and complementary strategy is *consuming differently*, which implies shifting towards goods or services with a lower environmental impact. This could involve purchasing "greener products", increasing expenditure on "services" rather than manufactured goods, or entering into arrangements such as energy service contracting and car sharing schemes. These strategies are frequently cited as having environmental benefits, although the empirical evidence to support such claims is often lacking. For example, a shift towards services and away from products may increase energy use, particularly if it involves higher standards of service, the extensive use of transport, or the construction of resource-intensive infrastructure such as telecommunications networks. In a recent review, Heiskanen and Jalas [15] concluded that the environmental benefits of product-to-service arrangements are modest at best while Suh [16] estimates that a shift to service-oriented economy could actually *increase* carbon emissions (although reduce the carbon intensity of GDP) owing to the heavy reliance of services upon manufactured commodities. Also, much of the observed decoupling in developed countries has been achieved by outsourcing manufacturing to developing countries. For example, official figures indicate a 5% reduction in the UK's carbon emissions between 1990 and 2004, but this changes to a 15% increase when the emissions embodied in international trade are accounted for [17].

Given the potential limitations of consuming efficiently and consuming differently, it seems logical to examine the potential of a third option—simply *consuming less* [18-20]. The key idea here is *sufficiency*, defined by Princen [20] as a social organising principle that builds upon established notions such as restraint and moderation to provide rules for guiding collective behaviour. The primary objective is to respect ecological constraints, although most authors also emphasise the social and psychological benefits to be obtained from consuming less.

While Princen [20] cites examples of sufficiency being put into practice by communities and organisations, most authors focus on the implications for individuals. They argue that "downshifting" can both lower environmental impacts and improve quality of life, notably by reducing stress and allowing more leisure time. This argument is supported by an increasing number of studies which show that reported levels of happiness are not increasing in line with income in developed countries [21, 22]. As Binswanger [23] observes: "…the economies of developed countries turn into big treadmills where people try to walk faster and faster in order to reach a higher level of happiness but in fact never get beyond their current position. On average, happiness always stays the same, no matter how fast people are walking on the treadmills".

Could an ethic of sufficiency provide a means of escaping from such treadmills while at the same time contributing to environmental sustainability?

According to Alcott [24], sufficiency implies both environmental motivation and purchasing power: "….those who are to alter their behaviour towards less consumption must be *able to* consume. Their purchasing power either remains unused or is itself reduced through working and earning less". Hence, the concept appears primarily applicable to the wealthy and is of little relevance for those suffering from absolute or relative poverty. But with increasing income inequality, spiraling levels of personal debt and the fallout from the 2008 economic recession, the proportion of people able to exercise such a choice is likely to be falling.

Adopting sufficiency as a guiding principle would require a major change in lifestyles. While most people would acknowledge that "quality of life" is not solely about material consumption, numerous psychological, economic and cultural obstacles can make it difficult for individuals to reduce current levels of consumption. For example, many people are partially "locked-in" to current consumption patterns owing to factors such as land-use patterns and physical infrastructures (which constrain choice in areas such as travel), the rapid obsolescence of consumer goods and the difficulty of reducing the number of hours of work. Consumption habits are also shaped by factors such as the search for status through the acquisition of symbolic "positional goods" (which creates a never-ending zero sum game), the rapid adaptation of aspirations to higher income levels (thereby reducing the happiness associated with that income), and what Jackson [25] calls the "almost perfect fit" between the search by producers for newer, better and cheaper products and the corresponding desire by consumers for novelty [18, 23]. In this context, the practice of sufficiency requires a minimum level of financial security, deeply held values and considerable determination. If adopted successfully by enough individuals, it could demonstrate a viable and attractive alternative to consumerism and begin to shift social attitudes in a number of areas. But since "luxury" consumption fulfils so many deep psychological needs, the widespread adoption of sufficiency appears unlikely to develop through voluntary action alone.

If the balance of factors encouraging or discouraging sufficiency were to change in favour of the former, it should become complementary to efficiency as a means of both improving quality of life and adapting to tightening ecological constraints. But to move the "sufficiency ethic" from the marginal to the mainstream is likely to require collectively agreed objectives, priorities, procedures and constraints that are institutionalised through government action in some form. This means that the most important agent of change is likely to be individuals acting as citizens in the political process rather than as "downshifting" consumers. Also, as Alcott [24] has pointed out, sufficiency is not immune from rebound effects, even when pursued at a national level. A successful "sufficiency strategy" will reduce the demand for energy and other resources, thereby lowering prices and encouraging increased demand by others which will partly offset the energy and resource savings. While this "sufficiency rebound" would improve equity in the consumption of resources, it would nevertheless reduce the environmental benefits of the sufficiency measures. But since the global "ecological footprint" already exceeds sustainable levels in many areas the global consumption of resources needs to shrink in absolute terms [26]. To achieve this and to effectively address problems such as climate change, will require collective agreement on ambitious, binding and progressively more stringent targets at both the national and international level.

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Mapping rebound effects from sustainable behaviours

Steve Sorrell, Sussex Energy Group, October 2011

I'm currently leading a research project on *Mapping rebound effects from sustainable behaviours*. This is collaboration between the Sussex Energy Group, SPRU, University of Sussex and the Centre for Environmental Strategy at University of Surrey. The project forms part of the *Sustainable Lifestyles Research Group* which is co-funded by the UK Department of Environment, Food and Rural Affairs and the Economic and Social Research Council.

The project is estimating the direct and indirect rebound effects associated with both energy efficiency improvements (e.g. buying a more fuel-efficient car) and behavioural changes (e.g. reducing car use) by UK households. It is investigating how these are influenced by income and other variables, assessing the level of uncertainty in the estimates and highlighting the policy implications. Below I summarise completed and planned work.

Work to date– Estimates of rebound effects for an average UK household

In the first stage of the project, estimates of the GHG intensities of 16 categories of household goods and services have been derived from the *Surrey Environmental Mapping and Attribution* framework (SELMA) [1-3] while estimates of the expenditure elasticities associated with those goods and services have been derived from *Surrey Econometric Lifestyle Environmental Scenario Analysis (*ELESA) model [4]. The latter uses data on total UK household expenditures and hence allows rebound effects to be estimated for an 'average' UK household.

To date, we have:

- Completed a **Working Paper** [5] that explains the nature and origin of rebound effects for households, summarises key concepts from the economic theory of consumer demand systems and reviews the existing (and very limited) literature on indirect rebound effects for households. This is currently being edited for submission to a journal.
- Completed a **conference paper** [6] and subsequent **journal paper** [7] that estimates the magnitude of rebound effects following three simple behavioural changes by an average UK household, namely: reducing food waste, turning the thermostat down 1°C and using walking or cycling for trips less than 2 miles. The paper estimates the rebound effects from these actions individually and in combination, together with the best and worst case outcomes.
- Developed preliminary estimates of the rebound effects following five types of energy efficiency improvement by an average UK household, namely: cavity wall insulation, loft insulation, tank insulation, energy efficient lighting, fuel efficient vehicles and solar thermal. These results were presented at the IAEE International Conference in Stockholm in June 2011. The rebound effects have been estimated over different time periods taking into account anticipated changes in household income and the GHG intensity of electricity generation. The estimates allow for both

the capital cost of the energy efficiency improvement and energy 'embodied' in the relevant investment (e.g. the cavity wall insulation).

Stage 2 – Estimation of rebound effects by income group

In the next stage of the project, we are estimating systems of consumer demand equations using data on household expenditure derived from the UK Living Costs and Food Survey (LCFS). This is annual survey of ~6000 UK households that provides detailed information on demographics, employment status, income and household expenditure on a wide range of goods and services. The objectives of this stage of the work are:

- To investigate how direct, indirect and total rebound effects vary with the 'equivalised income' of the household. Equivalised income reflects the extent to which households of different compositions (e.g. number of adults and children) require different levels of income to achieve the same standard of living. Indirect emissions account for larger proportion of total emissions for high income households while the marginal utility associated with key energy services (e.g. space heating) tends to be smaller. Hence, we hypothesise that indirect rebound effects will be larger for high income households while direct effects will be smaller. However, the net effect on the total (i.e. direct + indirect) rebound effect remains unclear.
- To examine how a greater level of commodity disaggregation can affect estimates of rebound effects. Since there are wide variations in GHG intensity both within and between commodity groups, there is considerable potential for the actual rebound effects to differ significantly from those estimated using aggregate data. By using a more fine-grained breakdown of commodity groups, the potential for larger or smaller effects can be explored.

The analysis will be based upon *Engel Curves* which describe how the share of household expenditure on a particular commodity group varies with household income and other variables. We intend to estimate Engel Curves for up to 30 commodity groups and to test and compare at least two functional forms. Rebound effects will be explored for a limited range of energy efficiency improvements and behavioural changes.

Stage 3 - Estimation of income and substitution effects

The above approaches only estimate the *income* effect of energy efficiency improvements. But such improvements will also lead to *substitution* effects with the overall rebound effect being the sum of the two Substitution effects could either add to or offset the income effects for both the energy service itself and for other goods and services. They may therefore either increase or decrease the rebound effect associated with individual commodities and services [5]. The overall rebound effect is hard to predict since it represents the net effect of income and substitution effects for the full range of goods and services consumed by households - which have widely varying GHG intensities.

To capture both income and substitution effects, it is necessary to estimate expenditure, own-price and cross-price elasticities for all commodity groups. This in turn requires the estimation of a system of demand equations using either time series data on an 'average' household (ONS) or pooled cross-sectional data individual households (LCFS). The former approach is more straightforward, but provides no scope for incorperating demographic variables and requires household expenditure to be aggregated into a relatively small number of commodity groups owing to the limited degrees of freedom, available. The latter approach can overcome these difficulties, but at the expense of greater complexity. Following Brannlund *et al.* [8], we propose estimating an Almost Ideal Demand System (AIDS) from ONS data covering the period 1992-2004. The model will be used to explore the impact of improving the energy efficiency of household gas use, household electricity use and automotive transport, both individually and in combination [8]. Efficiency improvements will be simulated as a reduction in price for the relevant energy commodity. The equations will be re-estimated following the price reduction and the results compared to the engineering estimates of GHG savings.

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