Determinants and Potential Magnitude of Economy-wide Rebound Effects: Overview of Key Findings from a Research Project Funded by the UK Economic and Social Research Council

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Economy-wide rebound effects

This project focussed on economy-wide rebound effects. Direct and indirect rebound effects are part of the economy-wide rebound effect but the distinction between the latter two in particular is not yet entirely clear in the literature. Where rebound is triggered by the reduction in the effective or implicit price of energy in response to an increase in efficiency in the use of energy (or a reduction in the price of energy services derived from a given physical input), we conclude that the three may be defined as follows:

- Direct rebound simply equates to the price elasticity of demand for energy (the change in demand for energy as the price changes), or the substitution effect in favour of energy. Thus these may be determined through econometric analyses of the relationship between price and demand.
- Indirect rebound equates to the energy embodied in additional goods and services that the user is able to consume as a result of the income effect. However, we would assert this only relates to 'economy-wide' or multiplier effects where nominal income and prices remain constant. Thus, they may be assessed using an input-output framework.
- Fuller economy-wide rebound effects will be triggered as incomes and prices change. Ultimately economy-wide rebound equates to the general equilibrium price elasticity of demand for energy, but this will be influenced by a number of factors and is determined ex-post rather than ex-ante through consideration of economy-wide rebound effects. Assessment of these requires a more flexible multi-sectoral economy-wide modelling framework that allows consideration of changes prices and quantities, supply and demand behaviour. In the rebound literature applied or computable general equilibrium (CGE) modelling frameworks have been used.

Use of CGE models in this project

This project set out to estimate the magnitude of rebound in the UK through empirical CGE modelling studies for Scotland and UK. However, in the progress of the research it became clear that the theory in terms of determinants of economy-wide rebound required further development and most of the work has involved using the empirical models for more analytical work. That is, using sensitivity analysis, running simulations under different assumptions in order to identify and consider the relative importance of different key determinants of and constraints on economy-wide rebound.

It is worth noting, that in the empirical analyses, we found it quite difficult to get an outcome of backfire (R>100%) so generally thinking about some energy saving, but just not as much as may have anticipated from the initial efficiency improvement. Where we did find backfire, unless we assumed key elasticities of substitution to be greater than one, these were driven by competitiveness effects resulting from productivity improvements. Our main backfire finds were found where energy efficiency

improvements take place in the heavily traded and energy intensive energy supply sectors in Scotland. However, before asserting that this is a likely outcome, we need to consider how to model energy supply sectors and pricing.

Again, the focus of this project became less to determine the likely magnitude of rebound in the UK national and regional economies than to first identify and understand the key determinants of economy-wide rebound.

Distinction between energy efficiency improvements in production and consumption behaviour
Most of the work in the project has looked at efficiency improvements in the use of energy in production. However, we have more recently begun to look at energy efficiency improvements in household (final) consumption activity. Note that it is important to note that by energy efficiency improvements we are referring to technological progress (i.e. a change in technology that permits more output to be gained for a given physical input of energy – not behavioural or price induced changes that cause us to use less energy without changing the output that is gained from physical input).

We have found that there is a key distinction in how increased energy efficiency transmits to the wider economy (i.e. determination of the economy-wide rebound effect) depending on whether it takes place in production or consumption activities:

- An energy efficiency improvement in production equates to a productivity change in the economy. The source of economy-wide rebound is also a source of economic growth - i.e. increased competitiveness
- Energy efficiency improvement in final consumption, on the other hand, transmits to supply-side of economy in two ways
    1. Through a shift in demand. If rebound is less than 100%, there will be a reduction in demand for energy and increase in demand for other goods and services (for a given nominal income - real income will rise, triggering income effects that govern indirect rebound)
        - Note that such a domestic demand stimulus may actually reduce competitiveness throughout the target economy. That is, there may be GDP growth, but with a crowding out of export demand. Thus, this is quite different to an improvement in productivity on supply side when energy efficiency improvements take place on production/industry side of economy. However, if the change in real income (and purchasing power) triggered by an energy efficiency improvement leads to reduced real wage demands, this becomes more similar to a productivity improvement (reducing the cost of labour supplied by households to the production side of the economy).
    2. If the demand for energy is reduced, this means falling demand for energy supply outputs. This may trigger (a) negative multiplier effects throughout the economy, particularly impacting energy supply itself given what is generally relatively high energy intensity of energy production, and (b) downward pressure on price of output in energy production. In the case of (b), if revenues fall as well, this will affect the return on capital and decisions regarding the replacement of worn out capital and installation of new capital. That is, it may trigger 'disinvestment' rather than investment in energy supply. Note that (a) may be considered in an input-output framework but (b) requires a CGE modelling framework where both changing prices and quantities may be considered.

Project focus on the supply-side response

Rebound is triggered by a demand response and this has been focus of much of the existing rebound research in the literature. However, in considering both indirect and economy-wide rebound, the supply response to changing demand, prices and incomes is crucial, particularly in energy supply. Our research (see the Turner, 2009, and Anson and Turner, 2009, references below in particular) shows that negative multiplier and disinvestment effects in energy supply will constrain the size of indirect and economy-wide rebound effects, possibly even causing them to be negative. In the case of disinvestment, this may lead to long-run rebound being larger in short run than in long-run.

These are key findings of the research and we have found these supply-side effects to be important whether energy efficiency improvements take place in production or consumption. However, there presence and importance depends on the nature of energy supply.

One issue is that it is important to be clear on what we mean by energy supply and use. For example, the price of oil is a world price. However, we don't consume crude oil. We consume refined/produced energy – e.g. petrol sold at pumps, electricity generated from renewable or non-renewable sources. The price of such *produced* energy (rather than energy as a primary input) is set in local markets.

This is what gives us the disinvestment process. When we have a reduction in demand for energy from an efficiency improvement (the initial efficiency effect), this pushes down price faced by energy suppliers. Now this may mean further impetus for economy-wide rebound. However, if demand is not sufficiently responsive (i.e. quantity demanded rises proportionately less than price falls), revenues will fall in energy supply sectors. If revenues fall, there is a decrease in the return on factors of production, particularly capital in what tend to be capital intensive activities. So the question is, how do energy suppliers and their investors respond?

In our research to date, we have focussed on domestic energy supply sectors (in same economy as where efficiency improvement takes place). However, where we import energy services, there may be be important interregional/spillover effects. This will be considered in future research.

Note on nature of energy efficiency improvements considered to date

To date, we have generally made the simplifying assumption that energy efficiency improvements are exogenous and costless in order to focus on response to change in implicit/effective price of energy (rebound trigger). This tends to be true across most CGE analyses of economy-wide rebound to date. However, we have done some work looking at potential costs (and use of revenues – see Allan et al, 2007, reference below). The key thing is that any cost of introducing imposed on energy user will reduce the effective price change that is the rebound trigger.

Intended future research

In the next stage of our research we will focus on relaxing the assumption that energy efficiency improvements are exogenous and costless. We have also begun to look at other key issues affecting the rebound trigger, such as whether, once technology installed, any further action is required by user to realise the efficiency improvement and consequent effective price change (e.g. adjusting heating controls after loft insulation has been installed), plus when/how the user recognises the latter (e.g. waiting for electricity bills and distinguishing impacts of efficiency improvement from other factors affecting the amount billed). On this latter, we have (in our household research – see the Lecca et al, 2011, reference below) begun to consider the appropriate use of price elasticities in considering even direct rebound (e.g wheter short-run or long-run elasticities are appropriate). However, this will also largely be the focus of future research.

To facilitate our continued rebound research, we have made an application to the European Research Council (ERC). This would involve a 5 year programme of research based at the Universities of Stirling and Strathclyde. In our application (which has reached the final stage of the competition) the empirical focus is primarily on UK and other EU. However, it need not be limited to in this way (or at country level – interest in sub-national, regions and cities, and also interregional). In the application, we already have some US focus, which involves looking at energy efficiency improvements through use of combined heat and power (CHP). The initial work proposed here would draw on a US dataset identified by Ian Lange (a colleague at the University of Stirling, formerly of the US EPA).

The research questions stated in the ERC application focus on

1. How energy efficiency improvements come about (i.e. relaxing the exogenous and costless, or 'manna from heaven' assumption
2. Estimating key parameters already identified as determining rebound. For example, estimating KLEM production functions. We have already done some comparative work for UK and US using Jorgenson and EU KLEMs datasets (working paper forthcoming) and estimating the elasticity of substitution between energy and non-energy goods for UK households (see the Lecca et al, 2011, reference below.
3. Gaining a better understanding and estimating key relationships on supply side – capital and labour as factors of production. On latter we have found, at least in a UK context (and this is likely to be true at EU level to) that labour migration behaviour crucial. However, the relationship between energy and capital (particularly where energy use and efficiency improvements are linked to durable goods) will also be key, and linking to the first research question above.
4. To focus on energy efficiency improvements in specific types of activity. We have proposed to start with CHP example in energy production. However, we have already looked at commercial transport example in Scotland but not in a very sophisticated way. A colleague at the University of Siena in Italy, a physicist named Franco Ruzzenenti, has suggested possible future work focussing on EU haulage with physical science input.
5. Modelling impacts of increased energy efficiency on key macro-level indicators of sustainability – e.g. carbon footprints, genuine savings etc.

Wish us luck – we get the funding decision in August!

Main rebound outputs to date:
(See also http://www.esrc.ac.uk/my-esrc/grants/RES-061-25-0010/read)

Papers in peer-reviewed journals:

'Energy Efficiency, Rebound Effects and the Environmental Kuznets Curve' by K. TURNER and N.D. HANLEY, accepted for publication in *Energy Economics*, December 2010, in press at http://dx.doi.org/10.1016/j.eneco.2010.12.002.

'Rebound and disinvestment effects in refined oil consumption and supply resulting from an increase in energy efficiency in the Scottish commercial transport sector' by S. ANSON and K. TURNER, *Energy Policy*, 37, 3608-3620. 2009.

'Negative rebound and disinvestment effects in response to an improvement in energy efficiency in the UK Economy, by K. TURNER, *Energy Economics,* 31, 648-666. 2009.

'Do increases in energy efficiency improve environmental quality and sustainability?' by N.D. HANLEY, P.G. MCGREGOR, J.K.SWALES and K. TURNER, *Ecological Economics,* 68, 692-709. 2009.

'The impact of increased efficiency in the industrial use of energy: a computable general equilibrium analysis for the United Kingdom', by G. ALLAN, N.D. HANLEY, P.G. MCGREGOR,

J.K.SWALES and K. TURNER, ***Energy Economics,*** Vol. 29(4), pp. 779-798. 2007.

Book chapters:

'Energy Efficiency', by G. ALLAN, M. GILMARTIN, P.G. MCGREGOR, J.K.SWALES and K. TURNER, in *International Handbook of Energy Economics*, edited by Lester Hunt, Edward Elgar ISBN 978-1-84720-352-6. 2009.

'Lessons from recent computable general equilibrium analyses of energy efficiency improvements: rebound and backfire effects' by G. ALLAN, M. GILMARTIN, P.G. MCGREGOR, J.K.SWALES and K. TURNER, in *Energy Efficiency Research Advances,* edited by David M. Bergmann, Nova Science Publishers, ISBN 1-60021-880-6. 2008.

'Modelling the economy-wide rebound effect' by G. ALLAN, M. GILMARTIN, P.G. MCGREGOR, J.K.SWALES and K. TURNER, in *Energy Efficiency and Sustainable Consumption: The Rebound Effect*, edited by Steve Sorrell and Horace Herring, Palgrave MacMillan, ISBN 0-23052-5342. 2008.

Discussion/working papers:

'Rebound effects from increased efficiency in the use of energy by UK households' by P. LECCA, J.K. SWALES and K. TURNER, *Strathclyde Discussion Papers in Economics,* No. 11-23. 2011. Available from: http://www.strath.ac.uk/media/departments/economics/researchdiscussionpapers/2011/11-23_Final.pdf

'An investigation of issues relating to where energy should enter the production function', by P. LECCA, J.K. SWALES, K. TURNER, *Stirling Economics Discussion Papers*, No. 2010-18. 2010. Available from: http://www.management.stir.ac.uk/documents/SEDP-2010-17-Lecca-Swales-Turner.pdf.

Non-technical papers:

'The rebound effect: some questions answered', by K.TURNER, M. KOERTH-BAKER, J.DEFENCE and C.Xin Cui. *Fraser Economic Commentary,* special issue (January 2011) titled 'Energy and Pollution', pp 37-45. Fraser of Allander Insitute, University of Strathclyde. 2011.

'Supply constraints on rebound effects from energy efficiency: negative multiplier and disinvestment effects' by K. TURNER, S. Anson, J. De Fence and J.K. Swales, *Fraser Economic Commentary*, Vol. 33, No. 3, pp 55-60. Fraser of Allander Institute, University of Strathclyde. 2010.

'Energy efficiency improvements and rebound effects: some lessons from the Scottish Case' by K.TURNER, G. Allan, P. McGregor and J.K. Swales, *Welsh Economic Review*, Winter, 2009. 2009.

'Energy efficiency and the rebound effect' by K. TURNER, *Fraser Economic Commentary*, Vol. 33, No. 2, pp. 47-54. Fraser of Allander Institute, University of Strathclyde. 2009.

All Fraser Economic Commentary issues may be downloaded at http://www.strath.ac.uk/frasercommentary/; and the Welsh Economic Review at http://www.cardiff.ac.uk/carbs/research/groups/weru/review.html.