Energy Efficiency Improvements and Rebound Effects: some lessons from the Scottish case

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Introduction – energy issues in Scotland

While the devolution settlement did not initially appear to allow it, it would seem that the Scottish Government has for some time been pursuing an energy policy that is distinctive from, and more ambitious in many respects than, the UK policy. Allan *et al* (2008) explore the motivation for and nature of a distinctive energy policy in Scotland. This paper notes the distinct structure and importance of the energy sector in Scotland and, indeed, the special emphasis given by the Scottish government to the potential role of particularly the renewable energy sector in stimulating economic growth (as a goal of its energy policy – see below). They detail the energy powers that have been reserved to Westminster and those that have been devolved to Scotland, as well as the main policy instruments of EU, UK and Scottish energy policies. The paper further considers how the latter may be employed to meet the objectives of Scottish energy policy under the constraints of the former.

Allan *et al* (2008, p. 47) consider the main goals or overarching objectives of Scottish Energy Policy (as explicitly identified in a statement to the Scottish Parliament on 31 May 2007 by the Energy Minister, Jim Mather) as covering four main issues (in bold font below):

- "Reduce carbon emissions, and so tackle climate change (**environment**).
- Ensure security of energy supplies *by fostering a vibrant, diverse and competitive energy sector that is rooted here in Scotland* (**security of supply**).
- Deliver energy at an *affordable* price for *both individuals and businesses* (**price**).
- *Ensure that energy policy allows the energy sector to continue to make its vital contribution to economic growth* (**growth**)".

Allan *et al* (2008) use italics to highlight where Scottish energy policy is distinctive from that at the UK level. However, even in terms of the first goal, to reduce carbon emissions, Scotland has set a very ambitious target of 80% reduction in emissions by 2050. Combined with the distinctive role attributed to the energy sector in stimulating economic growth, this leads Allan *et al* (2008) to conclude that Scotland's main challenge in the current context is how to achieve higher economic (and population) growth while simultaneously meeting such an ambitious carbon reduction target. They identify a number of potential candidate measures within the constraints of the energy powers devolved to Scotland and the policy instruments available. These include development of renewable energy sources; carbon capture and storage; combined heat and power; transport policies; microgeneration; and changing behaviour. Another potential measure, which forms the focus of this paper, is that of energy efficiency improvements.

Energy efficiency is given prominent focus in a number of the UK-wide instruments, including the Carbon Emissions Reduction Target, which replaced the Energy Efficiency Commitment. This obliges energy supplies to achieve targets in promoting reductions in carbon emissions in the household sector, whilst the Carbon Reduction Commitment, which will start in 2010, aims to encourage efficiency in large business and the public sector. The Carbon Trust, set up in 2001 with revenues from the Climate Change Levy, provides support for business energy efficiency programmes (and development of low carbon technologies). However, encouragement of energy efficiency has also been devolved to Scotland and there are Scottish-specific instruments in this regard. For example, there is the Energy Saving Trust, which is responsible for the promotion of cleaner fuels for transport, energy efficiency for buildings and homes, and small scale renewable energy projects. In addition, the Scottish office, funded by the Scottish Government, provides assistance through the Scottish Community and Householder Renewables Initiative. There is also Loan Action Scotland, through which the Scottish Government has provided funding of £3 million to be made available to small and medium sized enterprises (SMEs) in the form of a 'revolving' loan fund for capital investments in energy efficiency improvements for projects between £5,000 and £100,000 (at 0% fixed interest rate). Finally, there is the Central Energy Efficiency Fund, to which the Scottish Government has allocated funding of £24 million to provide loan funding for capital investments in energy efficiency improvements across the public sector in Scotland.

However, Allan *et al* (2008) go on to point out that while arguments that increases in resource (especially energy) efficiency reduce the burden of economic activity on environment are now widespread and influential in policy formulation, this is not guaranteed in an economy-wide context due to the potential for *rebound effects* in energy (or other resource) consumption as prices (and incomes) change. The question as to whether rebound effects may provide an explanation as to why total energy consumption in the UK has not fallen in line with increased energy efficiency was raised in a report from the House of Lords in 2005. In response, the UK Research Councils have funded research, first through the UK Energy Research Centre (UKERC) and now at the University of Strathclyde to investigate the conditions under which rebound effects may occur in the UK economy.

The aim of this paper is to provide an overview of the rebound argument and to present some results of economy-wide empirical analysis that has been carried out for the UK in a 3-year ESRC-funded project based in the Fraser of Allander Institute and Department of Economics at the University of Strathclyde.[1]

The rebound effect
The rebound argument (now commonly referred to as the Khazzoom-Brookes Postulate[2]) is not a new idea. Almost 150 years ago, in 1865 an economist named Stanley Jevons (Jevons, 1865) talked about a "*confusion of ideas*" regarding the productive use of fuel and diminished consumption. His argument was that if we increase the utility or benefit we get from something there is an impact on its implicit price. Thus, if we have an increase in (non price induced[3]) efficiency in use of energy, this lowers the implicit or effective price of energy (i.e. we can have more consumption/production per physical unit of energy at any given price level). Moreover, if we have local supply of energy, the decreased energy requirement per unit of consumption/production) will put downward pressure on actual energy prices, also giving further impetus for rebound.

With the initial improvement in energy efficiency, there is **technical/ efficiency effect**, where we need less energy to produce a given unit of output. However, as explained above, this triggers a decrease in the effective and possibly the actual price of energy, which in turn leads to four different types of (direct and derived) demand responses. The first three are specifically relevant to increased energy efficiency in production: **substitution effects** (where energy is substituted for other inputs, as it is now effectively cheaper); **output/competitiveness effects** (e.g. on exports - as the decrease in local production costs lowers output prices) **compositional effects** (a change in structure of output in the economy in favour of more energy intensive activities). Finally, we have **income effects** on household direct and indirect use of energy (even where households are not directly targeted with the efficiency improvement). All four of these put upward pressure on energy demand. The research reported below for Scotland suggests that, since Scotland trades heavily in energy, output/competitiveness effects are particularly important in the Scottish case where efficiency increases the use of energy in energy supply sectors, but substitution effects are more important where only non-energy supply sectors benefit directly from an increase in energy efficiency. Our research (see particularly Turner, 2009a, and Anson and Turner, 2009) suggests that there may also be additional *downward* pressure on energy consumption due to negative multiplier effects in energy supply as energy demands fall through the technical/efficiency effect and/or revenues in these sectors fall with actual energy prices.

Note that the basic rebound argument is not specific to energy. The same process would apply if, for example, there were an improvement in efficiency in the use of labour (and perhaps the rebound argument is easier to grasp in that context – we do not expect increased labour productivity to lead to mass unemployment; rather we expect economic activity, including employment, to benefit from what is basically a positive supply-side shock to the economy).

Ranges of the rebound effect
It is important to note that the presence of rebound effects in response to an increase in energy efficiency does not necessarily mean that overall energy consumption will *increase*. It may just mean that we need to work harder to gain desired reductions in energy consumption from increased energy efficiency. Table 1 shows four ranges of the rebound effect (see Turner, 2009a, or Anson and Turner, 2009, for fuller details).

The 0% rebound (R) case would seem unlikely as this would seem to imply absolutely no price responsiveness in the economy whatsoever.[4] The 0-100% range means that we have positive rebound, but a net decrease in energy consumption. Thus, it may be possible to adjust the size of the energy efficiency improvement to achieve a desired reduction in energy consumption if we are able to assess the likely magnitude of the rebound effect. For example, with 20% rebound a 10% efficiency improvement would imply actual energy savings of 8%. If a 10% reduction in energy consumption is required, the 20% rebound effect would have to be compensated for in setting the size of the energy efficiency improvement. In this simple example, a 10% reduction in energy consumption would require a 12.5% increase in energy efficiency with 20% rebound. Note that the magnitude of the rebound effect will be the same after the adjustment: we are simply compensating for it, not eliminating it. Moreover, the size of the rebound effect needs to be determined through economy-wide empirical analysis as it is likely to vary depending on (a) the economy in question, (b) the type of activity targeted with an energy efficiency improvement, (c) costs associated with introducing the energy efficiency improvement and (d) passage of time (adjustment of the economy) following the introduction of the efficiency improvement. Thus, the actual compensation required to entirely offset rebound would be difficult to quantify, particularly given issue (d), as the economy may take some time to adjust to a new equilibrium (see results below for Scotland).

However, no such compensation can be made in the bottom two cases in Table 1 where R is greater than or equal to 100%. Here the demand response to falling actual and/or implicit energy prices acts to entirely offset any energy savings from increased energy efficiency. Where we have a net increase in energy consumption (and, of course, energy-related pollution), this is an extreme case of rebound, referred to as backfire. Here a larger energy efficiency improvement will lead to a larger increase in energy consumption. Therefore, again, it is important to employ an empirical framework to quantify the economy-wide rebound effect: where backfire is a likely outcome, increasing the size of the energy efficiency improvement will be a counter-productive strategy.

An empirical question
The magnitude of rebound for any given efficiency improvement depends on relative importance of the different types of effect outlined above. This, in turn depends on the structure of the particular economy where the efficiency improvement occurs, openness to trade, demand responsiveness to changes in prices, supply constraints, which activities are targeted with the efficiency improvement etc. This means that analysis of potential macro-level rebound effects for any particular economy requires an empirical economy-wide modelling framework for that economy. This is commonly referred to as applied or computable general equilibrium (CGE) analysis (see Sorrell, 2007, and Hanley *et al*, 2009, and/or Turner, 2009a, for examples and fuller discussion).

Current research at the Department of Economics, University of Strathclyde
As explained in the introduction, leading on from the UKERC work reported in Sorrell (2007), the Fraser of Allander Institute economy-energy modelling team have been funded by the UK Economic and Social Research Council to conduct a project titled *'An empirical general equilibrium analysis of the factors that govern the extent of energy rebound effects in the UK economy'*. The duration of this project is 3 years, from October 2007 to September 2010 (ESRC Reference: RES-061-25-0010). The empirical work in this project has largely been focussed on the UK (e.g. Turner, 2009a) and Scotland (Hanley *et al*, 2009, and Anson and Turner, 2009), and to a lesser extent on the Spanish case (see Hernandez and Turner, 2009). From this research we have been able to draw more general analytical insights to help

Table 1: Ranges of the rebound effect

Rebound effect	Implication for energy efficiency improvement
0%	**All** of the energy efficiency improvement is reflected in a fall in the demand for natural energy units.
0 - 100%	**Some** of the energy efficiency improvement is reflected in a fall in the demand for natural energy units, but partly offset by increased (direct and derived) demand for energy as effective and/or actual energy prices fall.
100%	The reduction in energy demand from the efficiency improvement is entirely offset by increased demand for energy as prices fall.
> 100%	The energy efficiency improvement leads to an **increase** in the demand for energy in natural units that outweigh the reduction in demand from the efficiency improvement. Such a phenomenon is labelled as a **'backfire effect'.**

Table 2: Long-run Impact of Varying the Target of a 5% Energy Efficiency Improvement in Scottish Production (percentage change from base year)

	All sectors	Energy supply sectors	Non-energy supply sectors
	1-25	**21-25**	**1-20**
Total electricity consumption	1.15	2.34	-1.21
Electricity rebound effect (%)	*131.6*	*249.5*	*41.4*
Total non-electricity energy consumption	0.81	1.60	-0.82
Non-electricity energy rebound effect (%)	*134.1*	*243.8*	*34.8*

Note: See Appendix 1 for sector definitions.

development of the wider rebound research field, in both theoretical and empirical terms (e.g. the 'disinvestment effect' is established in Turner, 2009a).

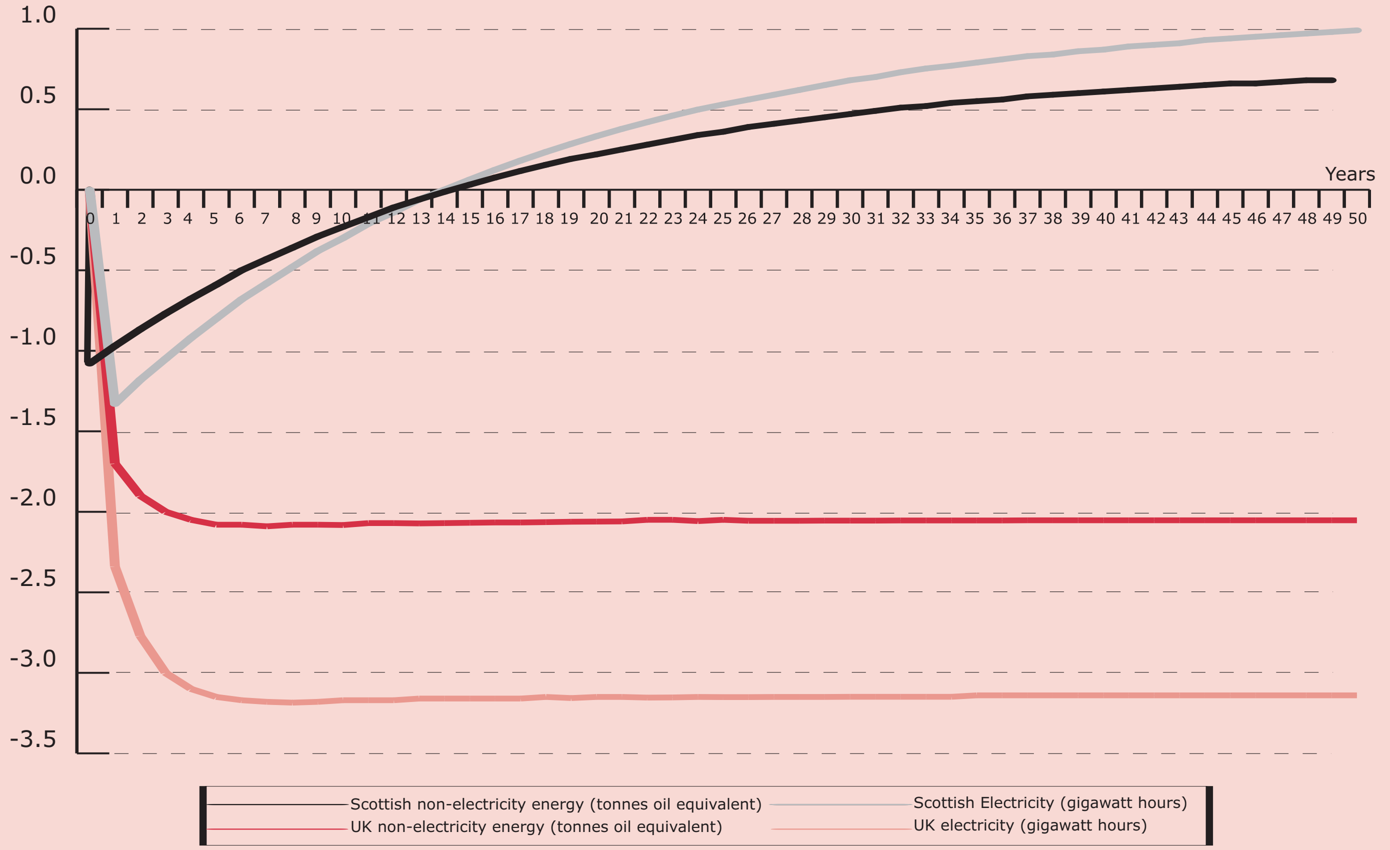
To date, the project has focussed on efficiency improvements in energy use in production. Work is forthcoming on energy efficiency increases in household energy consumption; however, at this stage we can anticipate that, in contrast to increased energy efficiency in production activities, there will be no direct positive supply shock (increased productivity and GDP), rather simply the reduction in demand that triggers price and income effects (although both of these factors may indirectly have a positive impact on GDP).

Our key empirical result for Scotland, illustrated in Figure 1, is that we find large backfire effects when local energy supply is targeted with/for efficiency improvement (these sectors are heavily traded), see Hanley *et al* (2009). In contrast, in the UK case rebound is more constrained by the supply response to falling prices, so that while the reduction in energy consumption is proportionately less than the increase in energy efficiency, there is still a net reduction (see Turner, 2009a, for more details on the UK results).

Figure 1 shows the results of simulating a very simple 5% increase in energy efficiency in all production sectors of the Scottish and UK economies respectively using our CGE models of the Scottish economy, SCOTENVI, and of the UK economy, UKENVI. In the initial stages of our research we have simulated very simple energy efficiency shocks as this allows us to identify and consider the key drivers of rebound effects. In these results we do not attempt to consider *how* the efficiency improvements may be achieved. This will also impact on the nature and magnitude of rebound and will be the focus of future research.

What the results in Figure 1 demonstrate is that, because of the system-wide response to falling actual and effective energy prices, particularly in an economy like Scotland (an energy producer and net exporter of electricity), reductions in energy consumption due to increased efficiency are likely to be partially or even wholly offset by increased demand for energy (i.e. rebound effects will occur). Indeed, the Scottish results are particularly striking. While the amount of electricity *consumed* in Scotland initially falls (in the early stages the output of the Scottish electricity sector increases as a result of increased *export* demand), 15 years after the introduction of the efficiency improvement it has risen above its initial level all things being

Figure 1: Percentage change in total energy consumption in Scotland and the UK in response to a 5% improvement in energy efficiency in all production sectors (applied to locally supplied energy).



equal. Non-electricity energy consumption follows a similar pattern, with the rise above the base year value occurring one period later.

There are two key clear implications of the results in Figure 1. First, it is important to examine the adjustment process of the economy in response to a shock such as increased efficiency in the use of energy in production. This is illustrated particularly in the Scottish case, where the short run impacts of the efficiency improvement are qualitatively different to the long run ones. Second, the qualitative difference in the Scottish and UK results demonstrate that it is important to carry out economy-specific empirical analysis.

As noted above, in the Scottish case the backfire effects (net increase in energy consumption across the Scottish economy) are driven by the fact that energy efficiency increases in all Scottish production sectors, including the relatively energy-intensive and heavily traded energy supply sectors. In Table 2, we show the long-run results of focusing the 5% increase in energy efficiency separately in energy supply and non-energy supply sectors (Appendix 1 gives a breakdown of the production sectors identified in the Scottish model). We define the long-run equilibrium where population and capital stocks have fully adjusted to the shock (this is not quite achieved in the Scottish case in Figure 1, even after the 50 years illustrated, but more than 85% of the adjustment in energy consumption has taken place at this point in time). The third column of Table 2 shows that backfire does not occur when we do not include the Scottish energy supply sectors in the energy efficiency improvement.

Hanley *et al* (2009) present fuller sensitivity results for the Scottish case, including the impacts of varying what we assume about the degree of price responsiveness in direct and derived energy demands.

Conclusions

This paper has considered the nature of what has come to be known as the 'rebound' effect in considering energy efficiency improvements as a means of reducing energy consumption (and associated pollutants, particularly greenhouse gas emissions). This is an important issue given the role attributed to energy efficiency improvements in achieving the objectives of energy policy in Scotland and the UK.

Our main conclusion is that the rebound effect is an empirical phenomenon and should be considered on a case-by-case basis for energy efficiency improvements (a) in different economies; (b) in different sectors/activities of any one economy; (c) in the context of different methods that may be adopted to increase energy efficiency and their associated costs; (d) the adjustment process of the economy. The core conclusion is that any reductions in energy consumption are likely to be proportionately smaller than the energy efficiency improvement and in some circumstances the net effect of increased efficiency may be an increase in energy consumption. Two main recommendations are that (a) energy efficiency improvements *should* be a policy objective, given the economic benefits that will result throughout the economy, but that (b) empirical estimates of potential rebound effects (and economic benefits) need to be factored into energy efficiency targets set in order to reduce energy consumption (and related emissions).

Finally, the reader is reminded that the results presented here are initial findings of the ongoing ESRC-funded project on examining the potential for and main drivers of rebound effects in the Scottish and UK economies. Fuller project details, outputs and results can be found at the project pages on the

ESRC Today web-site, which can be accessed via the following link: http://www.esrcsocietytoday.ac.uk/esrcinfocentre/viewawardpage.aspx?awardnumber=RES-061-25-0010. There will be a non-technical presentation of final project results at a stakeholder seminar to be held in the late summer of 2010. If you would like to attend this seminar, and/or to be placed on our mailing list to receive our project newsletter and other updates, please contact the author at karen.turner@strath.ac.uk.

Notes

1. More details on this project, along with all project outputs to date, can be found on the ESRC Today web-pages at http://www.esrcsocietytoday.ac.uk/esrcinfocentre/viewawardpage.aspx?awardnumber=RES-061-25-0010. Key project results to date can be found in Allan *et al* (2008), Hanley *et al* (2009), Turner (2009) and Anson and Turner (2009).
2. In recognition of two independent contributions by Brookes (1990) and Khazzoom (1980).
3. An example of a price induced change in energy efficiency may be the use of taxes to raise the price of and reduce demand for energy. This will not trigger the rebound effect. In this paper we are concerned with increased energy efficiency resulting from technological progress. However, price instruments such as energy taxes may be an appropriate tool to offset rebound effects and/or raise revenues that may be used to facilitate energy efficiency improvements.
4. However, our research has suggested that negative rebound effects - i.e. economy-wide reductions in energy consumption that are proportionately larger than the increase in energy efficiency - may be a possibility where there is local energy supply. This may occur as a result of negative multiplier effects in energy supply sectors as demand contracts in response to the initial efficiency improvement and/or disinvestment effects (shedding of capital stock) in energy supply if revenues fall with decreasing prices (see Turner, 2009a, and Anson and Turner, 2009).

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Appendix 1: Sectoral Breakdown of the 1999 Scottish AMOSENVI model

1	Agriculture
2	Forestry Planting and Logging
3	Fishing
4	Fish Farming
5	Other mining and quarrying
6	Oil and gas extraction
7	Mfr food, drink and tobacco
8	Mfr textiles and clothing
9	Mfr chemicals etc
10	Mfr metal and non-metal goods
11	Mfr transport and other machinery, electrical and instrument engineering
12	Other manufacturing
13	Water
14	Construction
15	Distribution
16	Transport
17	Communications, finance and business
18	R&D
19	Education
20	Public and other services
	ENERGY
21	Coal (Extraction)
22	Oil (Refining & distribution of oil and nuclear)
23	Gas
	ELECTRICITY
24	Renewable (hydro and wind)
25	Non-renewable (coal, nuclear and gas)