Indirect rebound involving embodied energy use in re-spending decisions: how do we treat negative multiplier effects in energy supply chains?

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Overview

A growing area of research into rebound effects from increased energy efficiency involves application of demand-driven input-output models to consider indirect rebound associated with re-spending decisions by households with reduced energy spending requirements. However, there is often a lack of clarity in applied studies as to how indirect rebound effects involving energy use embodied in supply chains have been calculated. We focus on a theoretical debate regarding the treatment of reduced energy requirements by energy producers and their up-stream supply chains as household energy spending decreases with improved efficiency. In existing literature there are different approaches as to what should be considered as part of our expectations regarding *potential energy savings* when estimating the potential energy savings from improved energy efficiency. Turner (2013) argues that potential energy savings should focus on what may be anticipated by decision makers, which is more likely to be potential *direct* engineering savings. On the other hand, Guerra and Sancho (2010) argue that in considering indirect rebound in an economy-wide context is appropriate to include direct *and indirect* energy supply chain requirements (pure quantity adjustments in supply chain requirements). We show that both the magnitude and direction of embodied energy rebound effects are highly sensitive to what is assumed to be part of 'potential energy savings' in the denominator of the conventional rebound calculation. In doing so, we also extend on the focus of most studies of rebound via embodied energy impacts to consider impacts on energy use and CO2 emission embedded in international supply chains and consider how these are reflected in alternative definitions of rebound.

Methods

An Inter-Regional Input Output (IRIO) approach is used to identify the embodied energy and CO_2 in the different points of global supply chains (both up-stream and down-stream). Our goal is to decompose high level energy and CO_2 impacts. The central model is given by:

$$EL\Delta Y(global) = \begin{bmatrix} e_i^1 b_{ij}^{11}\Delta y_j^1 & \cdots & e_i^1 b_{ij}^{1s}\Delta y_j^s & \cdots & e_i^1 b_{iN}^{1T}\Delta y_N^T \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ e_i^r b_{ij}^{r1}\Delta y_j^1 & \cdots & e_i^r b_{ij}^{rs}\Delta y_j^s & \cdots & e_i^r b_{iN}^{rT}\Delta y_N^T \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ e_N^T b_{Nj}^{T1}\Delta y_j^1 & \cdots & e_N^T b_{Nj}^{Ts}\Delta y_j^s & \cdots & e_N^T b_{NN}^{TT}\Delta y_N^T \end{bmatrix} \quad [1]$$

Where each e_i^r is a sectoral energy or carbon intensity, b_{ij}^{rs} are the elements of the interregional output multiplier matrix (Leontief invers), and y_j^s are final demands. Each element $e_i^r b_{ij}^{rs}\Delta y_j^s$ shows the energy or CO_2 embodied in the output generated by sector *i* in region *r* to support a change in the final demand for the output of sector *j* in region *s*. By applying the IRIO demand-driven model in this way it becomes possible to decompose the energy and CO_2 embodied in different global supply chains and observe the spatial and industrial distribution of rebound effects. This way it is possible to capture the magnitude of the negative rebound effects on the supply chain of a combined 'Electricity, Gas and Water Supply' (EGWS) sector (where household spending falls with increased energy efficiency) as well as the positive rebound effects on the supply chains of the sectors where monetary savings are reallocated. We use the tables and satellite accounts published by the World Input Output Database project (Timmer et al, 2015), therefore our observations are expanded to the global impact of spending reallocations by UK households.

In terms of considering the rebound measure we use equation [2], where, as standard in the literature, rebound (in percentage terms) is determined by the ratio of actual energy savings (AES) over potential energy savings (PES).

$$R = \left(1 - \frac{AES}{PES}\right) x100 \qquad [2]$$

Equation [2] reveals that the magnitude of the rebound, R, depends on what is included in PES. Linking back to equation [1] for a random region s, under a Turner (2013) approach, PES would include only the direct energy use associated with a change of Δy_j^s in the final demand for the output of sector j=energy supply. On the other hand the

Guerra and Sancho (2010) approach would mean that PES would include the direct change in energy use due to Δy_j^s plus the sum of all the elements down the column of [1] for sector j=EGWS (including energy supply) in region s.

Results

We take a simple example of how a 10% efficiency improvement in the UK household demand impacts the output of UK EGWS sector (where almost all UK household energy spending is concentrated). In terms of direct 'engineering' savings UK households save consume 152,591 tera joules (tj) less energy giving a total monetary saving of $5,526m. Using [1], this leads to actual energy savings (AES) of 347,651 tj at the domestic part of the UK EGWS up-stream supply chain and 363,364 tj globally. Under different interpretations of potential energy savings (PES) this is translated to a rebound effect ranging from a negative rebound of -138% globally if the approach favoured by Turner (2013) is adopted but rebound of 0% under the Guerra and Sancho (2010) approach (where the full energy supply chain quantity adjustment is treated as PES).

We then explore three simple illustrative scenarios of household re-spending of the monetary savings, i.e. $5,526m. These are two 'heat or eat' and one 'turning lights into flights' scenarios. To keep things simple, we make the assumption that UK households reallocate the whole of the amount saved on one sector. Comparing the two 'heat or eat' scenarios it was found that re-spending the savings to UK Hotels and Restaurants (HR), the 'eat out scenario', causes an erosion of the energy savings that is mainly located on the domestic part of the UK HR up-stream supply chain, an increase of energy use by 10,492 tj within the UK compared to 5,218 tj overseas. On the other hand if the savings are allocated to the global Food, Beverage and Tobacco (FBT) sector, the 'eat in' scenario, the erosion of the energy savings is greater than that of the UK HR scenario and the biggest impact is on the non-UK part of the global FBT up-stream supply chain. Here an increase of energy use by 23,598 tj is observed overseas compared to an increase of 11,300 tj within the UK. In the 'turning lights into flights' scenario the savings are spent on the global Air Transport (AT) sector. In this case we observe an even greater erosion of the energy savings, mainly supported by the increase of energy use outside the UK, an increase of 65,306 tj. In all three scenarios then the re-spending decisions trigger an increase of energy use. However in every scenario the increase is not enough to offset the energy savings resulting from the improved energy efficiency and therefore we continuously observe net energy savings.

In terms of the measurement of the rebound effect, the result in each case is dependent on what is considered as PES. Under the Guerra and Sancho (2010) approach all the respending decisions lead to positive rebounds, lower than 100% but increasing as the households reallocate their savings on more energy-intensive sectors. On the other hand the approach favoured by Turner (2013) suggests that there is always a net negative rebound, albeit one that is eroded as households spend on other sectors with varying energy-intensities. For example in the 'eat in' scenario and focusing on the energy use, using the Turner (2013) approach the rebound at UK level is -120%, (i.e. still greater energy savings relative to initial expectations), whereas the Guerra and Sancho (2010) approach gives us a rebound of 3%, implying that we observe energy savings that are smaller than was initially expected.

Conclusions

Our work has explored a simple case of 10% improvement in UK household energy efficiency and has shown that it leads to significant indirect reductions in the UK EGWS sector's supply chain. Furthermore it was shown that even if the households re-spend all their monetary savings on other sectors, there are always net energy savings yet decreasing as the re-spending sectors become more energy-intensive. However one of the key arguments that we have raised is the usefulness and transparency of rebound as an indicator when different approaches are used to calculate rebound in different studies. Solely relying on rebound to inform interested parties on the final impact of improved energy efficiency could lead to misleading conclusions if decision makers are not clear on just how it has been calculated. Rebound as an indicator is heavily related to the definition of what should be considered as PES and therefore without a standard definition of PES the results vary significantly depending on each researcher's interpretation.

Download the full working paper that this abstract is based on at http://strathprints.strath.ac.uk/55426/. A non-technical policy brief focusing on alternative measures to rebound can be downloaded at our EPSRC project web-site, http://cied.ac.uk/research/impacts/energysavinginnovations.

References

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