Estimating the U.S. Economy-wide Rebound Effect with Input-Output Life-Cycle Assessment

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1. Introduction

Governments consider energy efficiency standards and incentives as cost-effective policies to lower greenhouse gas emissions that contribute to climate change. However, there is uncertainty on how much an investment in energy efficiency may yield in terms of expected energy savings. These savings might be eroded due to the rebound effect – and there is a large debate about the magnitude of this effect. The rebound effect is a controversial topic has traditionally been a footnote in assessments of the efficacy of energy efficiency policies (Gillingham *et al.*, 2006), although recent years have seen a surge of interest in the understanding the extent of the rebound effect (Sorrell, 2009, Guerra and Sancho, 2010).

A basic definition of the rebound effect compares actual energy savings (AES) with potential energy savings (PES) [Guerra and Sancho, 2010; Allan et al., 2006]:

$$R = 1\text{-}AES/PES \qquad (1)$$

This basic definition of the rebound effect applies at either the microeconomic or macroeconomic level, as seen in Figure 1.

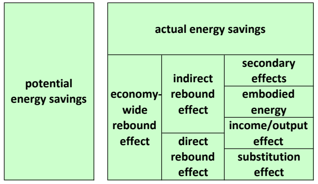

Figure 1: Rebound Taxonomy. Reproduced from Sorrell, 2007.

This study estimates the impact of energy efficiency investments in different goods/services and associated fuels on the direct and indirect rebound effects for the U.S. using an economic input-output lifecycle assessment (IO-LCA) model, which uses Bureau of Economic Analysis (BEA) data (www.eiolca.net; Hendrickson et al., 2006; BEA, 2002), for the 2002 U.S. economy.

2. Methods

The IO-method of economic analysis, consists of a production function or total requirements matrix, A (which is [428 x 428] and unitless), which uses industry transactions in the form of purchases of goods and services by one industry from other industries. The final demand for goods, Y ([428 x 1] in million $), relates to intermediate goods, X ([428 x 1] in million $) in the following way:

$$X=(I-A)^{-1}Y \qquad (2)$$

In the Environmental Input Output Lifecycle Assessment model (EIO-LCA) the input-output data are coupled with data about direct environmental emissions of industries to form the vector, E ([12 x 428]) . Then, to estimate the total emissions throughout the supply chain, Z, one can use the following relationship:

$$Z = EX = E(I-A)^{-1} {*} Y \qquad (3)$$

IO analysis can be used to model the re-spending of energy cost savings on other goods, to represent indirect rebound effects due to higher effective income. We model energy efficiency by considering an exogenous decline in the final demand Y for energy in $M by *t* , where *t* is between 0 and 1.

$$Y_{eff\_energy\ sector}[\$]=(1-\tau)Y_{base\_energy\ sector}[\$] \qquad (4)$$

$$PES[tonCO_2e]=Z_{base}-Z_{eff\_noRespend}=E(1-A)^{-1}(Y_{base}-Y_{eff\_noRespend}) \qquad (5)$$

$$AES[tonCO_2e]=Z_{base}-Z_{eff\_Respend}=E(1-A)^{-1}(Y_{base}-Y_{eff\_Respend}) \qquad (6)$$

2. Methods (cont.)

To represent indirect/economy-wide AES, we define four cases to redistribute the cost savings from the lower electricity or gasoline usage:

- responding energy cost savings in proportion to current spending,
- responding energy cost savings entirely in the lowest energy-intensity or GHG-intensity sectors to form a lower bound for the economy-wide energy or GHG rebound (direct rebound is not modelled in this case),
- responding energy cost savings entirely in the highest energy-intensity or GHG-intensity sectors to form an upper bound for the economy-wide energy or GHG rebound (direct rebound is not modelled in this case), and
- treating energy cost savings as a form of income, and using income elasticities of demand to allocate respending to the remaining 426(for gasoline efficiency) to 427 (for electricity efficiency) sectors.

3. Data

We model the final demand vector, Y, for the base case, which represents average U.S. household consumption using two data sources to represent average household demand for goods and services, including energy (1) GDP per capita, for a single year (2002), and (2) U.S. Consumer Expenditure Survey (CEX, 2003)

Using GDP per capita as a measure of average household demand, relies on the assumption of a closed economy, in which all outputs from the commercial, industrial, and government sectors are consumed (in the same year) by residential households. The GDP data is allocated into 428 industrial sectors, which match the scope of the IO-LCA model, and thus we chose to use this data source because it suffers from a lower sector misallocation error.

The Consumer Expenditure Survey (CEX) is an annual compilation of data from two separate surveys: a bi-weekly Diary survey and a quarterly Interview survey and. The Diary survey is conducted with a nationally representative sample of households over two consecutive weeks, and collects expenditure data on smaller food, personal care, and household expenses. The Interview Survey is conducted with a nationally representative sample of households over five consecutive quarters, and collects data on expenditures on recurring expenses such as rent and utilities, and larger purchases, such as property, automobiles, durable goods, and medical expenses. The Interview Survey also collects before- and after-tax income data, however these are less reliable due to recall errors. The CEX is divided into 74 expenditure categories, and has to be allocated into the 428 EIO-LCA sectors, and thus suffers from a larger sector misallocation error. We chose to use the CEX data to investigate how rebound effects vary by income group, depending on their different consumption bundles. The CO2 emissions and expenditure distributions for different types of consumption goods are found in Figure 2.

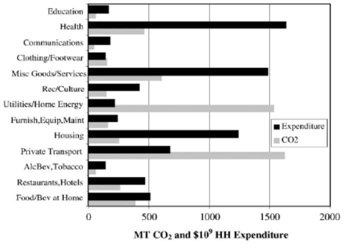

Figure 2: CO2 emissions and expenditures from the Consumer Expenditure Survey. Reproduced from Weber et al., 2008.

4. Results

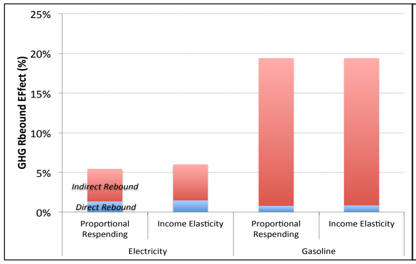

Figure 3: Direct emissions rebound is small relative to indirect/ economy-wide emissions rebound.

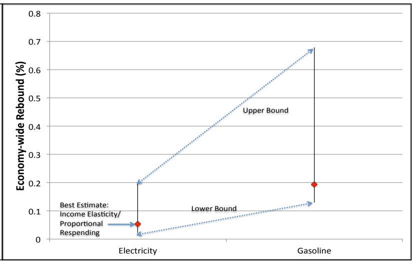

Figure 4: There is a wide range in the potential economy-wide emissions rebound depending on respending patterns.

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4. Results (cont.)

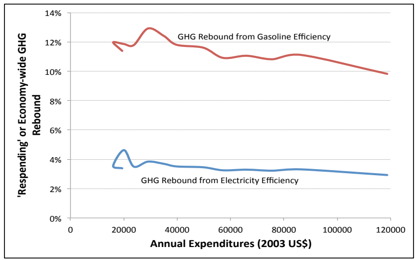

Figure 5: Rebound effects vary slightly by income.

5. Conclusion

The results from this study show that GHG rebound effects are higher for efficiency investments in lower GHG-intensity fuels than in high GHG-intensity fuels such as electricity because there is a greater chance of respending energy cost savings in a higher GHG-intensity good. Thus, this analysis would suggest that appliance standards for electricity consuming devices and electric utility demand-side management programs may have less of a GHG rebound than CAFÉ standards for automobiles, for every percentage of energy cost savings. Thus, from a societal perspective, appliance standards and demand-side management programs may be more cost-effective than CAFÉ standards. However, lower oil consumption may be important for reasons other than reducing GHG emissions, such as national security and geopolitics.

In the case of proportional or income elasticity respending, 4-12% (using CEX data) or 1-20% rebound effect is possible. These results also show that even in the upper bound case, with all respending in the greatest GHG-intensive sector, there is a high rebound of 68%, which is less than backfire, or rebound > 100%. The upper bound scenario of respending all energy cost savings in industrial gases is unlikely for households, so a realistic upper bound is probably much less. The possibility of backfire seems small given the respending mechanism of the rebound effect.

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