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Empirical estimates of the direct rebound effect: A review

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ABSTRACT

Improvements in energy efficiency make energy services cheaper, and therefore encourage increased consumption of those services. This so-called direct rebound effect offsets the energy savings that may otherwise be achieved. This paper provides an overview of the theoretical and methodological issues relevant to estimating the direct rebound effect and summarises the empirical estimates that are currently available. The paper focuses entirely on household energy services, since this is where most of the evidence lies and points to a number of potential sources of bias that may lead the effect to be overestimated. For household energy services in the OECD, the paper concludes that the direct rebound effect should generally be less than 30%.

1. Introduction

Improvements in energy efficiency make energy services cheaper, and therefore encourage increased consumption of those services. This so-called direct rebound effect offsets the energy savings that may otherwise be achieved. For example, consumers may choose to drive further and/or more often following the purchase of a fuel-efficient car because the operating cost per kilometre has fallen. Similarly, consumers may choose to heat their homes for longer periods and/or to a higher temperature following the installation of loft insulation, because the operating cost per square metre has fallen. The extent to which this occurs may be expected to vary widely from one energy service to another, from one circumstance to another and from one time period to another. But any increase in energy service consumption will reduce the 'energy savings' achieved by the energy efficiency improvement. In some circumstances, it could offset those savings altogether—an outcome that has been termed 'backfire'.

Direct rebound effects are the most familiar and widely studied component of the overall or economy-wide rebound effect (Sorrell, 2007) which also involves various indirect effects (for example, the energy associated with *other* goods and services whose consumption has increased as a result of the energy efficiency improvement). Beginning with Khazzoom (1980), there have been a series of estimates of the direct rebound effect for different energy services (Greening and Greene, 1998). These studies are extremely diverse in terms of the definitions, methodological approaches and data sources used. Also, despite growing research activity, the evidence remains sparse, inconsistent and largely confined to a limited number of consumer energy services in the United States—notably personal automotive transport and household heating. The main reason for this is the lack of suitable data sources for other types of energy service in other sectors and countries. In addition, interpretation of the evidence is greatly hampered by the use of competing definitions, measures, terminology and notation. Many studies do not mention the direct rebound effect at all, but nevertheless provide elasticity estimates that may, under certain assumptions, be used as proxy measures of that effect. Taken together, these features inhibit understanding of the direct rebound effect and the appropriate methodological approach to estimating its magnitude in different circumstances, as well as making it difficult to identify the relevance of particular studies.

This paper provides an overview of the methodological approaches to estimating direct rebound effects and reviews the evidence that is currently available. It updates an earlier review by Greening et al. (2000) and seeks to clarify a number of issues that were raised therein. The underlying research is reported in detail in Sommerville and Sorrell (2007) and Sorrell and Dimitropoulos (2007a). The paper focuses entirely on energy services in the household sector, since this is where practically all of the research has been undertaken. As a result, the conclusions do not provide guidance on the magnitude of direct rebound effects in other sectors, nor on the economy-wide rebound effect, which is fully discussed by Sorrell (2007) and Sorrell and Dimitropoulos (2007c).

Section 1 describes the operation of the direct rebound effect, highlighting some key issues concerning the measurement of this effect and the conditions under which it may be expected to be larger or smaller. Sections 2 and 3 describe the

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Box 2–Direct rebound effects for clothes washing

Davis (2007) provides a unique example of an estimate of direct rebound effects for household clothes washing—which together with clothes drying accounts for around one-tenth of US household energy consumption. The estimate is based upon a government-sponsored field trial of high-efficiency washing machines involving 98 participants. These machines use 48% less energy per wash than standard machines and 41% less water.

While participation in the trial was voluntary, both the utilisation of existing machines and the associated consumption of energy and water was monitored for a period of two months prior to the installation of the new machine. This allowed household specific variations in utilisation patterns to be controlled for and permitted unbiased estimates to be made of the price elasticity of machine utilisation.

The monitoring allowed the marginal cost of clothes washing (P_G) for each household to be estimated. This was then used as the primary independent variable in an equation for the demand for clean clothes in kg/day (S). Davis found that the demand for clean clothes increased by 5.6% after receiving the new washers, largely as a result of increases in the weight of clothes washed per cycle rather than the number of cycles. While this could be used as an estimate of the direct rebound effect, it results in part from savings in water and detergent costs. If the estimate was based solely on the savings in the energy costs of the service (P_S), the estimated effect would be smaller. This suggests that only a small portion of the gains from energy efficient washing machines will be offset by increased utilisation.

Davis estimates that time costs form 80–90% of the total cost of washing clothes. The results, therefore, support the theoretical prediction that, for time-intensive activities, even relatively large changes in energy efficiency should have little impact on demand (Binswanger, 2001). Similar conclusions should, therefore, apply to other time-intensive energy services that are both produced and consumed by households, including those provided by dishwashers, vacuum cleaners, televisions, power tools, computers and printers.

Table 1
Econometric estimates of the long-run direct rebound effect for household energy services in the OECD.

End-use	Range of values in evidence base (%)	'Best guess' (%)	No. of studies	Degree of confidence
Personal automotive transport	3–87	10–30	17	High
Space heating	0.6–60	10–30	9	Medium
Space cooling	1–26	1–26	2	Low
Other consumer energy services	0–41	<20	3	Low

Third, while improved energy efficiency may increase the demand for energy services (e.g. you could drive further after purchasing an energy-efficient car), it is also possible that the anticipated high demand for energy services may increase the demand for energy efficiency (e.g. you purchase an energy-efficient car because you expect to drive further). In these circumstances, the demand for energy services depends on the energy cost of energy services, which depends upon energy efficiency, which depends upon the demand for energy services (Small and Van Dender, 2005). Hence, the direct rebound effect would not be the only explanation for any measured correlation between energy efficiency and the demand for energy services. This so-called 'endogeneity' can be addressed through the use of simultaneous equation models, but these are relatively uncommon owing to their greater data requirements. If, instead, studies use a single equation without the use of appropriate estimation techniques, the resulting estimates could be biased. Several studies of direct rebound effects could be flawed for this reason.

Finally, consumers may be expected to take the full costs of energy services into account when making decisions about the consumption of those services and these include the *time costs* associated with producing and/or using the relevant service—for example, the time required to travel from A to B. Indeed, the increase in energy consumption in industrial societies over the past century may have been driven in part by attempts to 'save time' (and hence time costs) through the use of technologies that allow tasks to be completed faster at the expense of using more energy. For example, travel by private car has replaced walking, cycling and public transport; automatic washing machines have replaced washing by hand; fast food and ready meals have replaced traditional cooking and so on. While not all energy services involve such trade-offs, many important ones do (compare rail and air travel for example). Time costs may be approximated by hourly wage rates and since these have risen more rapidly than energy prices throughout the last century, there has been a strong incentive to substitute energy for time (Becker, 1965). If time costs continue to increase in importance relative to energy costs, the direct rebound effect for many energy services should become *less* important—since improvements in energy efficiency will have an increasingly small impact on the total cost of energy services (Binswanger, 2001). This suggests that estimates of the direct rebound effect that do not control for increases in time costs (which is correlated with increases in income) could potentially overestimate the direct rebound effect. Box 1 shows how this could be particular relevant to direct rebound effects in transport. Similar reasoning suggests that the direct rebound effect may decline as the mean level of energy efficiency improves as energy costs should form a declining fraction of the total cost of energy services.

The consideration of time costs also points to an important but relatively unexplored issue: increasing time efficiency may lead to a parallel 'rebound effect with respect to time' (Binswanger, 2001; Jalas, 2002). For example, faster modes of transport may encourage longer commuting distances, with the time spent commuting remaining broadly unchanged. So in some circumstances energy consumption may be increased, first, by trading off energy efficiency for time efficiency (e.g. choosing air travel rather than rail) and second, by the rebound effects with respect to time (e.g. choosing to travel further).

9. Summary

In summary, the accurate estimation of direct rebound effects is far from straightforward. A pre-requisite is adequate data on energy consumption, energy services and/or energy efficiency

Table A5
Econometric estimates of the direct rebound effect for household heating using single equation models.

Author/year	Short-run rebound effect	Long-run rebound effect	Country	Data	Functional form	Estimation technique	Comments
Douthitt (1986)	10–17%	35–60%	Canada	Cross-section 1980–1981 SS: 370	Double log	OLS	RE estimated from $\eta_{P_E}(E_{heat})\|_{\varepsilon_h}$. Elasticities vary with price level.
Hsueh and Gerner (1993)	35% (electric)	–	US	Cross-section 1980–1981 SS: 1028 gas, 253 Electricity	Double log	OLS	Equation for E_{total} incorporating engineering variables determining cost of S_{heat}. RE estimated from $\eta_{P_E}(E_{total})\|_{\varepsilon_h}$
	58% (gas)						
Schwarz and Taylor (1995)	–	1.4–3.4%	US	Cross-section 1984–1985 SS: 1188	Double log	OLS	Measure of thermostat setting (T_i) and level of thermal insulation allows estimates of $\eta_{\varepsilon_h}(T_i)$ and $\eta_{\varepsilon_h}(S_{heat})$.
Haas et al. (1998)	–	15–48%	Austria	Cross-section SS: ~400	Double log	OLS	RE estimated from a number of sources, including $\eta_{P_E}(E_{heat})$, $\eta_{\varepsilon_c}(E_{heat})$ and $\eta_{\varepsilon_h}(E_{heat})$.
Guertin et al. (2003)	–	29–47%	Canada	Cross-section 1993 SS: 440 (188 gas; 252 elec.)	Double log	OLS	Use of frontier analysis to estimate ε_c. RE estimated from $\eta_{P_S}(S_{heat})$ where $P_S = P_E/\varepsilon_c$.

Table A6
Econometric estimates of the direct rebound effect for household heating using multi-equation models.

Author/year	Short-run rebound effect	Long-run rebound effect	Country	Data	Functional form	Estimation technique	Comments
Dubin and McFadden (1984)	25–31%		US	Cross-section 1975 SS: 313	Discrete-continuous	Logit (discrete) and instrumental variables (utilisation)	Electrically heated households. RE estimated from $\eta_{P_E}(E_{heat})$. No control for ε.
Nesbakken (2001)	15–55% (average 21%)		Norway	Cross-section 1990 SS: 551	Discrete-continuous	Logit (discrete) and instrumental variables (utilisation)	Various fuel combinations. RE estimated from $\eta_{P_E}(E_{heat})$. No control for ε.
Klein (1987, 1988)	25–29%		US	Pooled cross-section: 1973–81 SS: 2157	Household production	3SLS	Simultaneous estimation of a cost function for S, a demand function for S and an equation for the relative share of capital and fuel. RE estimated from $\eta_{P_S}(S_{heat})$, which in turn is estimated from $\eta_{P_G}(S_{heat})$.

Table A7
Econometric estimates of the direct rebound effect for space cooling.

Author/year	Short-run rebound effect	Long-run rebound effect	Country	Data	Functional form	Estimation technique	Comments
Hausman (1979)	4%	26.5%	US	Cross-section 1978 SS: 46	Discrete-continuous	Nested logit (discrete) and instrumental variables (utilisation)	Room air-conditioners individually metered. RE estimated from $\eta_{\varepsilon_c}(E_{cool})$. Use of instrumental variables avoids endogeneity bias.
Dubin et al. (1986)	1–26%		US (Florida)	Cross-section 1981 SS: 214–396	Discrete-continuous	Nested logit (discrete) and instrumental variables (utilisation)	RE estimated from $\eta_{\varepsilon}(E)$. ε is a composite of ε_c and ε_h. Quasi-experimental design ensures ε_c is exogenous. Comprehensive data on structural characteristics allows ε_h to be estimated with an engineering model.