Manuel Frondel, Jörg Peters, and Colin Vance
IDENTIFYING THE REBOUND: THEORETICAL ISSUES AND EMPIRICAL EVIDENCE FROM A GERMAN HOUSEHOLD PANEL

Manuel Frondel: Division Chief Environment and Resources, Leiter des Kompetenzbereichs Umwelt und Ressourcen, RWI Essen, Hohenzollernstr. 1-3, 45128 Essen,
Phone: 0049 (0)201 8149 204, Fax: 0049 (0)201 8149 200, e-mail: frondel@rwi-essen.de
Colin Vance: RWI Essen, Hohenzollernstr. 1-3, D-45138 Essen, Germany,
Phone: +49-201-8149237, Fax: +49-201-8149200, e-mail: vance@rwi-essen.de
Peters Joerg: RWI Essen, Hohenzollernstr. 1-3, D-45138 Essen, Germany,
Phone: +49-201-8149247, Fax: +49-201-8149200, e-mail: peters@rwi-essen.de

The improvement of energy efficiency is often said to be one of the most promising options to reduce both the usage of energy and associated negative externalities, such as greenhouse gas emissions. Nevertheless, while technological efficiency improvements may confer benefits via reduced per-unit prices of energy services, they may also offset reductions in energy consumption by increasing the demand for these services. It is plausible, for instance, that the owner of a new, more fuel-efficient car will *ceteris paribus* drive more in response to lower per kilometer traveling costs relative to other modes. This increase in service demand is called the “rebound effect”', alternatively referred to as “take back” of efficiency improvements. Khazzoom (1980) was among the first to study the rebound effect at the microeconomic level of households, focusing on the effects of increases in the energy efficiency of a single energy service, such as space heating and individual conveyance. The rebound, however, is a general economic phenomenon, diminishing potential savings of time-saving technologies as well as of innovations that may reduce the usage of resources such as water.

The significance of the rebound, whose principle mechanisms are based on price and income effects embedded in economic theory, has been hotly debated among energy economists ever since then. Part of the controversy is due to the fact that there are several mechanisms at work that may offset potential energy savings triggered by efficiency improvements. Accordingly, three principal types of rebound effects have been identified and distinguished in the economic literature, the direct and indirect rebound effect, as well as general equilibrium effects.

The direct rebound effect describes the increased demand for an energy service whose price shrinks due to improved efficiency. This substitution mechanism in favor of the energy service works exactly as would the price reduction of any commodity other than energy and suggests that price elasticities are at issue when it comes to the estimation of the direct rebound effect. Besides the substitution effect, there is an income effect: lower per-unit cost of an energy service *ceteris paribus* imply that real income grows. In other words, more money can be spent on other goods and services, which may also require energy, so that the respective use of energy might rise. This is the indirect rebound effect. Finally, innovations, such as James Watt’s famous steam engine, that increase society's income may cause substantial general equilibrium effects. Given that both indirect and general equilibrium effects are difficult to quantify, the overwhelming majority of empirical studies confines itself to analyzing the direct rebound effect.

Though the basic mechanism is widely accepted, the core of the controversy lies in the identification of the *magnitude* of the direct rebound effect. Some analysts, most notably

Lovins (1988), maintain that rebound effects are so insignificant that they can safely be ignored. Other authors argue that these effects might be so large as to completely defeat the purpose of energy efficiency improvements (Brookes, 1990, Saunders, 1992). A major reason for the diverging results of the empirical studies is that there is no unanimous definition of the direct rebound effect. Instead, several definitions have been employed as determined by the availability of price and efficiency data, making comparisons across studies difficult. An additional feature distinguishing studies is whether potentially relevant factors such as capital cost and time usage of energy services are included in the analysis. The resulting variety of definitions used in the economic literature is summarized and analyzed in an illuminating way by Dimitroupoulos and Sorrell (2006), who argue that it is particularly due to the omission of potentially relevant factors that the size of the direct rebound effect might be frequently overestimated in empirical studies.

Departing from the theoretical grounds provided by Becker's (1965) classical household production function approach and drawing on a panel of household travel data, this paper focuses on estimating the rebound effect from variation in the fuel economy of household vehicles. Several features distinguish our analysis. In the theoretical section of the paper, we catalogue three commonly employed definitions of the direct rebound effect, derive empirically relevant propositions therefrom, and prove these propositions using Becker's household production model. The empirical section of the paper builds directly on the theoretical discussion by presenting econometric estimates corresponding to each of the three definitions of the rebound effect. A key aim here is to highlight the identification problem pertaining to the rebound, which is of a twofold nature due to, first, the variety of definitions and, second, the multitude of estimation techniques available for exploiting a given empirical data set. As a consequence, we provide a range of estimates by taking account of both the various definitions of the direct rebound effect and the diverse estimation techniques available for panel data analysis.

Our results, which range between 56% and 66%, indicate a rebound that is substantially larger than the typical effects obtained for the U.S. Based on household survey data. Greene, Kahn, and Gibson (1999:1), for instance, find a long-run ``take back'' of about 20 % of potential energy savings, confirming the results of other U.S. studies using national and or state-level data. While this issue has received relatively less scrutiny in the European context, our results are also substantially larger than those of Walker and Wirl (1993), who estimate a long-run rebound effect of 36 % for Germany.

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