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Analysis

Energy savings and the rebound effect with multiple energy services and efficiency correlation

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ABSTRACT

The rebound effect, or the increased use of energy services following an increase in the efficiency of that service, is widely studied in the literature, but it is usually only considered in a single-service environment. Such a framework ignores the potentially significant indirect rebound effects that occur through increased purchasing power for other services and does not allow for joint efficiency improvements across many services, what we call "efficiency correlation." We develop a household production model with two energy services and distinct but simultaneous efficiency changes to test the implications of efficiency correlation on net energy elasticities and the rebound effect. Positively correlated efficiency choices across end-uses not only increase technically feasible energy reductions but also drive additional rebound responses that erode these savings. Model simulations suggest that the rebound effects through the efficiency correlation channel are just as large as traditional direct and indirect rebound effects reported in the literature, though they are offset by added technical energy savings. Moreover, we find that negative correlation can significantly reverse any energy savings (e.g. a household installs energy-saving window panes but then trades in their sedan for a SUV), but current Federal efficiency standards make this scenario unlikely. This paper offers new insight into a host of additional behavioral responses to efficiency improvements, particularly the incidence of efficiency correlation across different energy services, and highlights its implication for realized energy savings.

1. Introduction

Energy efficiency has been promoted by a host of policy organizations as a cost effective means for reducing energy use and respective externalities (EPA, 2008; ILG, 1997; NRC, 2009). Over the last several decades, energy efficiency programs, standards, and policies have become increasingly common at private municipalities and all levels of government. There are nearly 1500 energy efficiency programs in the U.S., and most programs administer efficiency by providing financial incentives for technology adoption (DSIRE, 2013). Spending on demand-side management more than doubled between 2005 and 2010 (EIA, 2013a), perhaps buoyed by an $11B Federal investment in energy efficiency as part of the American Recovery and Reinvestment Act of 2009 (DOE, 2013).

Supporting arguments for efficiency often assume that energy demand reductions are driven exclusively by changing the technical operating efficiency of durable goods (for examples see NRC, 2009; EPA, 2008; Creyts et al., 2007), i.e., an increase in efficiency leads to an equivalent decrease in energy use ($\Delta \mathit{Efficiency} = -\Delta \mathit{Energy}_s$). These approaches are often called "bottom-up" or "engineering economic" assessments because they apply engineering analysis to assess individual technologies. Bottom-up assessments often rank-order efficient technologies by the levelized cost of energy saved, then estimate the technically feasible energy saved assuming all technologies in a given market are replaced or retrofitted (an approach that often uses "conservation supply curves"). Recent applications of bottom-up assessments include NRC (2009), Creyts et al. (2007), Azevedo (2009), and Blackhurst et al. (2011).

However, neoclassical economics indicates that consumers respond to efficiency (an implicit decrease in the price of energy services) by increasing quantity demanded, eroding some of the technically feasible savings (a behavior termed the "rebound effect"). The rebound effect for households is typically divided into direct and indirect effects. The direct rebound effect is the behavioral change following an efficiency improvement for a single end-use. The direct effect is defined as the elasticity of a single energy service with respect to its own efficiency, and is typically derived by differentiating the definition of technical efficiency ($E = S/\varepsilon$) with respect to efficiency as per Eq. (1):

$$\eta_\varepsilon(E) = \frac{\partial E}{\partial \varepsilon}\frac{\varepsilon}{E} = \frac{\partial\left(\frac{S}{\varepsilon}\right)}{\partial \varepsilon}\frac{\varepsilon}{\frac{S}{\varepsilon}} = \left[\frac{\partial S}{\partial \varepsilon}\frac{1}{\varepsilon} - \frac{S}{\varepsilon^2}\right]\frac{\varepsilon^2}{S} = \left[\frac{\partial S}{\partial \varepsilon}\frac{\varepsilon}{S} - 1\right] = \eta_\varepsilon(S) - 1 \qquad (1)$$

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where E denotes the energy input, while S denotes energy services, and ε denotes efficiency. The "engineering economic" approach assumes $\eta_\varepsilon(S) = 0$, modeling the elasticity of energy use with respect to efficiency as unity (e.g. $\Delta Efficiency = -\Delta Energy$). Eq. (1) is conceptually appealing in demonstrating that some efficiency gains are "taken back" as additional energy services and has informed much of the literature on the direct rebound effect (see Sorrell and Dimitropoulos, 2008; review of empirical estimates in Sorrell et al., 2009; Greene, 2012). On the other hand, the indirect effect for households is typically attributed to re-spending on other goods and services, largely due to an increase in purchasing power caused by the decrease in the effective-price of energy (in economics, this is referred to as the "income" effect). Since energy (and carbon) is used in the supply chain of essentially any good and service, re-spending will erode the net effects of efficiency. In combination with broader structural shifts for producers, these re-spending patterns can lead to "economy-wide" rebound affects (Azevedo et al., forthcoming; Herring et al., 2009). On these grounds, researchers and policy makers have emphasized that rebound challenges the efficacy of efficiency to reduce net energy consumption (Alcott, 2010; Barker et al., 2009; Jenkins et al., 2011).

Literature reviews show wide ranges in magnitudes for the direct rebound from nearly 0 to 100% (see review in Sorrell et al., 2009); however, considerable variation in methods, study samples, and research quality may explain these inconsistent results. In particular, previous researchers suggest higher rebound for lower income households due to higher expected marginal utility for energy services. By assuming that the price of energy is exogenous and efficiency changes are constant, some researchers assert that the direct rebound, $\eta_\varepsilon(S)$, is approximately negative of the own-price elasticity of demand for energy services: $\eta_\varepsilon(S) = -\eta_p(E)$ (Greene, 2012; Sorrell et al., 2009; Binswanger, 2001). These assumptions serve as the basis for much of the empirical estimates of direct rebound.

Research on indirect rebound is more sparse. Binswanger (2001) conceptually challenged restricting rebound analyses to a single-service, applying indifference curves to qualitatively demonstrate that indirect rebound may be much larger for energy-intensive substitutes and that the income effect may be much more significant than price responses. More recently, Saunders (2013) echoed this sentiment. A few studies use Eq. (1) to estimate the increase in expenditures (income and substitution effects) following discrete efficiency changes (Druckman et al., 2011; Freire-González, 2011; Thomas and Azevedo, 2013). These studies using environmentally extended input–output analysis to empirically estimate indirect rebound as the energy embodied in the production of goods and services associated with an increase in expenditures following a discrete efficiency change. These studies estimate the magnitude of "direct + indirect" effects ranging from 30%–40% for the U.S. and 30%–50% for Spain.

Several researchers emphasize that technical change can also increase time efficiency, especially for transportation services. Binswanger discusses two rebound effects for time saving technologies. First, time saving technologies often require more energy to increase the speed of service, as demonstrated by faster transportation modes. Second, since time is a constraint similar to income, time saving technologies produce substitution effects similar to an income increase. Jalas (2002) emphasized this latter effect in estimating the potential rebound from a time savings services for Finnish households. While the author acknowledges empirical limitations, results suggest that some "time saving interventions" like eating out and using cars for shopping might produce a rebound.

The above models of rebound are limited to a discrete efficiency change for a single service. However, households are subject to ongoing, positively correlated efficiency improvements within and across end uses. While exogenous to households, Federal efficiency standards for a broad array of end-uses have consistently increased over the last several decades. Endogenous, positively correlated efficiency change is also observed in above-code technology choices. The average U.S. household has three above-code efficient technologies installed; 40% have more than five; 90% have more than two. Fig. 1 indicates that above code technology installations and consistent above code installations increase with income (EIA 2012). The energy technology installations in Fig. 1 reflect installations across different energy services that are not mutually exclusive.

For the purposes of this paper, we call consistent, positively correlated exogenous and endogenous efficiency change "efficiency correlation". While the literature demonstrates limited insight into the

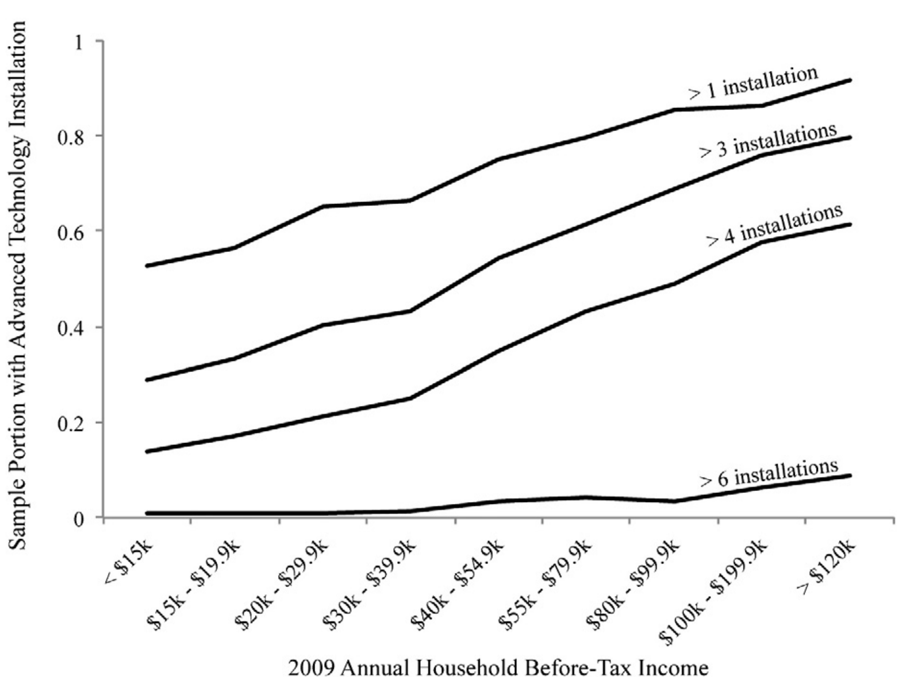

Fig. 1. The portion of approximately 12,000 U.S. homes with up to demand-side technology installation. Advanced technologies include Energy Star Applicant (3), triple-pane without, a heat pump a programmable thermostat, well-insulted building shell, compact florescent bulbs, and weatherized shell.