Implications of the Rebound Effect for Multi-Energy Efficient Applicance Adopters: A Comparative Analysis of RECS and Pecan Street Data

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Introduction

The impact of energy efficiency on energy demand has been a controversial issue in the research community, as different models have been proposed to assess the potential outcomes of increasing energy efficiency, especially for U.S. households' appliances and their relationship with short and long-run energy demand. It seems beneficial to the U.S. demand market that an increase in energy efficiency leads to an increase in energy demand. However, when we try to analyze the neoclassical consumer's behavior, the scientific world agrees that the improvement of energy efficiency reduces the cost of energy services and thus increases the energy demand (and the energy consumption). This phenomenon has a negating effect on the energy savings that were intended by adopting energy efficient technologies. Commonly called "the rebound effect," this disturbing but clearly relevant effect has been evaluated by several studies, using economic and econometric models that encompass different parameters, ranging from price elasticities to capital investments (i.e., expenditures on durables like audio and video goods, computer goods, kitchen appliances, etc.).

The earliest conceptualization of the rebound effect was undertaken by Stanley Jovens in 1865 in The Coal Question, which describes the drop in coal prices as a result of an increase in the efficiency of the steam engine, allowing coal to become an affordable commodity for more people and for new uses, ultimately increasing coal consumption.[1] It was not until 1980 that the rebound effect resurfaced in Khazzoom's description of a single commodity case, where an expected 1 percent increase in technological efficiency caused less than a 1 percent decrease in energy demand, primarily due to the price elasticity of demand and the decrease in price per energy unit, making it more attractive to increase the frequency of using that particular technology.[2]

Berkhout et al,[3] Hertwich,[4] Herring and Roy,[5] and Oikonomou et al[6] describe the rebound effect as first-order (direct) and second-order (indirect):

- *First order:* A direct price and income effect increases consumer and producer purchasing power due to improvements in energy efficiency (e.g., producing more fuel efficient vehicles reduces price per distance traveled, where an increase in demand for travel or other energy services becomes more attractive).
- *Second order:* Indirect industries are affected by the increased demand of another industry due to reduction of production costs or price of energy services (e.g., as travel demand increases, maintenance and vehicle production industries will be needed).

Within first-order rebound, Khazzoom,[7] Greening et al,[8] Hertwich,[9] Barker et al,[10] Sorrell,[11] and Oikonomou et al[12] further define the RE through four specific categories:

- *Direct (income) effect:* An increased demand for use of energy services due to a decrease in price per energy unit attributed to greater efficiency (e.g., setting indoor temperature below normal levels due to the energy efficiency of a new air conditioning system).
- *Indirect (substitution) effect:* An increased use of energy services due to the decrease in price per energy unit attributed to greater efficiency in another technology (e.g., significantly reducing your electricity bill by to switching to energy efficient appliances could provide the funds necessary to indulge in energy intensive vacations, such as a road trip or airfare to another city).

Past empirical analyses that evaluate the magnitude of the rebound effect assess it at less than 30% for household services and personal transportation; thus net energy savings are still achieved.[13] However, some of these analyses suffer from a small size dataset or incomplete characterization of households. By including a large range of households, as well as detailed surveys and audits as provided by the Pecan Street Project, we think that the regression and prediction results will enable us to describe and have a better understanding of the correlation between the technologies choices and energy consumption among U.S. households.

Currently our research compares the statistical significance and difference of the rebound effect between single energy efficient technology (low) adapters and multiple energy efficient technology (high) adapters across two data sets: the Residential Energy Consumption Survey (RECS) and the Pecan Street Project in Austin, Texas, which compiles data from multiple sources, including home drawings; energy audits; household surveys; and monitors of electricity use, on-site electricity production, natural gas, and water. This study focuses particularly on household consumption and the implications of current and/or future policies that promote greater energy efficiency or energy conservation. Additionally, the two data sets are compared as a way to validate the accuracy of the RECS data set, since it is analyzed and used to derive energy consumption projections that influence nation-wide policies.

Data Description and Methodology

The residential sector claims 22% of the total energy consumption of 2011, compared to 19% for the commercial sector, 28% for the transportation sector and 31% for the Industrial sector. However, the residential sector has been growing at a steady annual rate just under 0.4%.[14] Few international studies, including Austria[15] and South Korea,[16] have focused particularly on household appliances other than heating/cooling systems. This study focuses on direct rebound within the residential sector, specifically including the following energy efficient appliances: Energy Star refrigerators, dishwashers, clothes washing machines, windows other than single-pane, central or wall/window air conditioning systems, and adequate attic insulation.

A multiple linear regression (MLR) analysis was performed on the RECS and Pecan St. data sets, using disaggregated data for available and comparable built-environment, behavioral, and technological efficiency parameters. The RECS data yielded 142 households within urban settings in Texas, while only 57 homes were used within the Pecan St data. The MLR used for the RECS and Pecan Street data sets are respectively illustrated in the equations below with Equation 1 and Equation 2:

Results, Discussion and Policy Implications

Table 1 shows the spread of electricity consumption for both data sets, where the RECS consumption is an order of magnitude greater than that recorded by the Pecan Street Project. This could be due to a low number of samples (57 for the Pecans Street data, compared to 142 for the RECS data), but may reflect discrepancies in RECS calculations. Further analysis requires evaluation of RECS assumptions and methodology, as well as a greater sample from the Pecan Street Project.

A comparison between the RECS and Pecan St data regression model further points to the existence of discrepancies (Table 2). The Pecan St. data should produce more accurate results since location-specific unobservables are held constant. The only indicators that were individually statistically significant are the home size (square-footage), the number of household members who reside in the home, the age of the home owner, the household income, having a dishwasher, and being a low-adapter of energy efficient technologies. However, only home size is statistically significant across both data sets and the RECS data displays economic significance twice that of the Pecan Street data. Another

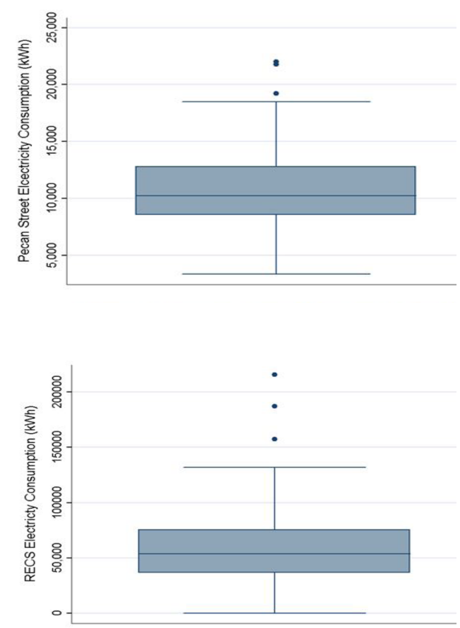

Table 1. A comparison of the box plots of electricity consumption reported by the Pecan Street Project (above) and the RECS (below(.

$$Electricity_{RECS} = \beta_0 + \beta_{CDD}CD65 + \beta_1 SQFT + \beta_2 HouseAge + \beta_3 HouseAgeSize + \beta_4 HHMem + \beta_5 ATHOME + \beta_6 HHAGE + \beta_7 INC + \beta_8 INCsq + \beta_9 esFrig + \beta_{10} esDWash + \beta_{11} esAirCond + \beta_{12} esWind + \beta_{13} esInsul + \beta_{14} One \quad \text{Equation 1}$$

$$Electricity_{PECAN} = \beta_0 + \beta_1 SQFT + \beta_2 HouseAge + \beta_3 HouseAgeSize + \beta_4 HHMem + \beta_5 ATHOME + \beta_6 HHAGE + \beta_7 INC + \beta_8 INCsq + \beta_9 esFrig + \beta_{10} esDWash + \beta_{11} esAirCond \; \beta_{12} esWind + \beta_{13} esInsul + \beta_{14} One \quad \text{Equation 2}$$

Figure 1. Multiple linear regression equations used for the Residential Energy Consumption Survey (RECS) and Pecan Street data sets.

	No Appliance Consideration		Energy Efficient Appliance Consideration	
	RECS	PECAN	RECS	PECAN
R-squared	0.33	0.47	0.36	0.51
β_1	38531	3049	43986	3399
CDD	-0.53	-	-0.37	-
SQFT	6.35**	3.69*	7.32**	3.78*
HouseAge	1174	-23.8	1262	-22.9
HouseAgeSize	-4.00	0.01	-4.99	0.01
HouseholdMem	-379*	171.3	-332**	231
WorkAtHOME	-6019	-	-7945	-
HouseholderAge	16780***	-16.88	20914	-19.9
Income	827***	0.01	574	0.01
IncomeSq	0.02	0.01	0.03	0.01
esDWash			-13081*	-216
esCWash				353
wsWind			-2682	565
esAirCond			5891	-1121
esInsul			-1601	-817
LowAdapter			-8408	2416***

*Significance at p > 0.01 and **Significance at p> 0.05. ***Significance at p> 0.10

Table 2. Marginal increments of household energy demand, in kWh, where the left-side columns compare RECS data to the Pecan St data and the right columns question rebound effects when comparing low and high adapters of energy efficient appliance. For example, an additional household member causes a decrease in energy demand by 300 to 400 kWh per year using the RECS data. Similarly, for the Pecan Street data, a household that has only one energy efficient appliance (low-adapter) consumes about 2,400 kWh per year more than a household that has more than one energy efficient appliance (high-adapter).

odd result is that the RECS data shows that an additional household member actually decreases energy consumption (a variable shown to be statistically significant), when intuitively it seems an additional household member would increase the electricity demanded. The Pecan Street data shows statistical significance with low-adopters of energy efficient technologies, emphasizing that the rebound effect is greater among low-adopters. The comparison of the regression model is reported in Table 2.

Future analysis that addresses these inconsistencies could include providing indicators that control for the total number of appliances. One possibility is through the STRINT approach, where structural parameters (number of appliances) and intensities are distinguished.[17] Also, a cross-section regression analysis could be performed on the RECS data, since 2009 data is now available and a panel regression could provide more robust results for the Pecan St. data. Similar to Kaza ,[18] a quintile regression approach could also be pursued to understand the effect of high/low adopters on different tiers of energy consumers.

Clarifying the relationship between low-adopters, high-adopters, and energy demands is a crucial objective to better understanding and providing effective policies that reduce energy demands. Using RECS is only beneficial if it is accurate in describing population behaviors. The Pecan St. Project has the potential to validate RECS and provide a more comprehensive characterization of consumer behavior in view of climate change. It would also provide a better foundation to estimate the rebound effect on multiple technologies. Bridging these gaps could provide the tools necessary to construct prices and standards that account for the rebound effect, while not penalizing consumers who are early and/or high adopters of energy efficient technologies.

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