A Top-Down Economic Efficiency Analysis of U.S. Household Energy Consumption

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Executive summary

Energy efficiency and related demand management policies help mitigate the impacts of climate change by reducing the use of fossil fuels and reducing the energy sector's vulnerabilities to climate change impacts. Over the past forty years, federal and state-level energy efficiency policies (or standards) have been applied to household appliances, the corporate average fuel economy, electric demand-side management programs, weatherization assistance, and building codes. The U.S. residential housing sector accounts for approximately 21% of total primary energy consumption and 20% of domestic carbon dioxide emissions. Building construction codes and standards regulate the energy efficiency of newly constructed homes or commercial buildings and the energy efficiency requirements specific to renovations, major refurbishments, and the enlargement of buildings. Such codes generally provide minimum building requirements for heating and cooling systems and for any construction or renovations to the housing envelope that leads to energy savings.

The present study analyzes the determinants of household-level energy use and how efficient each household uses energy compared to a sample of similar homes within the United States. Examining the within-sample efficiency of usage is important as past studies have found that households with similar demographic and economic characteristics, located in the same geographic region, differ considerably in their energy use.

Given the variation in energy use between households, our paper provides a method to explore the relationship among social, economic, behavioral, and physical factors that determine the pattern and levels of household energy consumption. To this end, we draw on elements from two branches in the economics literature – the energy efficiency gap and the analysis of the determinants of household-level energy efficiency.

This study differs from the recent economic literature associated with analyzing energy efficiency, as our research is not based on a quasi-experimental method or field experiment. A behavioral or experimental framework to examining household energy efficiency is often described as a "bottom-up approach," whereas a neoclassical economic model is often described as a "top-down approach." Bottom up implies that the empiricist does not necessarily make any prior assumptions about a household's behavior or response to a policy, but instead simply observes the response of a treated household in comparison to a similar but non-treated household. Top down, on the other hand, implies that the empiricist formulates prior assumptions about household behavior; such as, the household agent is rational and seeks to minimize costs or produce its energy services efficiently.

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Despite the readers preconceived notions of a behavioral versus a neoclassical approach, each separate framework contains various assumptions, which lead to differing strengths and weaknesses. The current research makes no attempt of arguing in favor of one approach over the other. Instead, we view the separate frameworks as the flip side of the same coin – in terms of analyzing the behavioral response associated with household-level energy efficiency gains – and we proceed by analyzing this phenomenon using a neoclassical economic approach.

This study offers several unique contributions to the literature. One, we use a unique data set obtained from the 2009 U.S. Energy Information Administration's Residential Energy Consumption Survey. The survey contains responses from over 12,000 households across the U.S. providing an incredibly rich cross section of disaggregated data. Two, we develop a theoretical model that demonstrates that a household's energy consumption is affected by the types of energy technologies used within the household. However, the households' energy technologies are not directly observed within the available data, so we use a data-driven method to identify subsets or classes of housing that consume similar levels of energy, arguably based on similar types of household energy technologies. We demonstrate that by dividing the sample into classes, the model offers more accurate measures of efficiency of energy consumption (within each household). Four, the modeling approach allows us to estimate a household-by-household efficiency index of consumption. Five, we condition the cost frontier analysis on a set of other covariates that would potentially affect a household's energy efficiency of consumption, including geographic location, climate zones, and several other household characteristics such as home size and residential makeup.

This research confirms the findings of earlier studies, that demographic composition and the house's structural characteristics are important determinants of household-level energy consumption and efficiency. In addition to demographics and building characteristics, we control for climate-related factors that affect household demand for energy services. Our results suggest that state-level energy building code regulations, on average, induce a one-to-four percent marginal increase in household energy consumption. This increase in energy consumption is often referred to as a (partial) rebound effect.

Our findings suggest that recently promulgated energy building code regulations appear to have led to an increase, instead of a decrease, in average annual energy consumption. The current study – based on economic, not engineering analysis – sheds light on the fact that potential savings may change due to behavior responses. These findings are fairly robust to different demographic characteristics of occupants, physical characteristics of the home, geographic regions, climate data, and unobserved heterogeneity within the underlying technologies (for energy services) available in the home. The reduction in the effective costs could lead to an unintended consequence in which households end up consuming more energy resources as a result of the inducement to retrofit the home. Our findings are not entirely bleak, as we do find some evidence where energy code regulations serve their purported intent by reducing overall average energy consumption for some of the observations. From a regulatory standpoint, it is important for policymakers to be cognizant of the fact that governmental policies can change consumers' incentives, which ultimately may lead to an increase in energy consumption.

Keywords Energy efficiency; energy rebound effect; household energy consumption.

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