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Returns to residential energy efficiency and conservation measures: A field experiment

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HIGHLIGHTS

- Uses a novel field experiment to test the efficacy of residential energy efficiency measures.
- Randomization eliminates endogeneity concerns and rebound effects.
- Insulation and financial incentives reduce annual natural gas consumption by nearly 20%.
- Reductions are most significant with a combination of incentives and programmable thermostats.
- Ambient temperature in homes receiving incentives is as much as 4 degrees F lower than the control.

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ABSTRACT

Residential energy conservation is a key component of contemporary energy and climate change policy in the US and elsewhere. Comparisons of the relative effectiveness of measures aimed at reducing residential energy consumption are made challenging, however, by the endogeneity of technology and energy use decisions. In this paper we describe a novel small-scale field experiment that uses randomized treatments to estimate the returns to three types of energy conservation measures in institutionally owned homes. The results from the experiment indicate considerable reductions in natural gas consumption associated with the installation of attic insulation and the provision of incentives for conservation. The results are supported by observations of ambient indoor temperature data, which show that households receiving incentives significantly reduce their temperature settings—especially when coupled with access to a programmable thermostat. The study will ideally provide guidance for institutions and communities considering energy efficiency measures and for future researchers designing randomized experiments to study residential energy use.

1. Introduction

In the face of growing concerns regarding climate change, the extraction and transport of conventional fuels, and energy market volatility, demand-side management through energy efficiency is now at the forefront of energy policy and planning. Given that single-family homes account for nearly one fifth of energy consumption in the US, measures aimed at residential energy efficiency could play an important role in reducing energy use. Household actions to improve energy efficiency have the potential to lower expenditures on energy inputs and reduce negative environmental impacts. Despite the possibility of generating “win–win” outcomes for households and the environment, effectively measuring energy savings associated with household energy efficiency measures is challenging.

There is an extensive literature that provides explanations for the so-called efficiency gap that characterizes the observed low rates of investment in energy conservation technologies at the household level, despite engineering estimates that purport large potential savings (e.g., Sutherland, 1991; Jaffe and Stavins, 1994; Gillingham et al., 2009). Only a small set of studies, however, actually attempt to measure realized savings associated with energy efficiency measures to determine the extent to which a true energy efficiency gap exists.

Measuring the savings associated with energy efficiency measures based solely on engineering estimates is insufficient because these estimates ignore the actual realization of implementation costs, end-user behavior and performance characteristics under actual usage. Measuring energy efficiency savings using naturally

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occurring data is also difficult, however, due to the potential for endogeneity in energy choices. Endogeneity issues are of concern when the choice of efficiency measure is correlated with the subsequent intensity of energy use. For example, if conservation minded households are both more likely to install insulation and lower their thermostat settings.

As a result of the shortcomings associated with both engineering estimates of energy savings and estimates based on naturally occurring data, a recent article by Allcott and Greenstone (2012) suggests that “Future research should utilize randomized controlled trials and quasi-experimental techniques to estimate the impacts of energy efficiency programs…” (p.27). In this study, we describe a novel field experiment that tests the efficacy of household energy conservation and efficiency measures. Specifically, we utilize data from a two-year field experiment involving 24 single-family homes owned by an academic institution and rented to students that do not pay utility bills. The treatments compare the relative effects of two types of energy efficiency investments, attic insulation and programmable thermostats, as well as a financial incentive-based policy. While the sample of homes and occupants in the study is limited in scope, the study provides a template for the type of randomized experimental design that represents an important step in the energy efficiency literature.

The randomization of efficiency treatments in the sample of homes in our experiment eliminates endogeneity concerns. In addition, since residents of the homes do not pay utility bills, financial motivations for reducing energy use can presumably be controlled for. This eliminates the possible impact of rebound effects that might occur if lower marginal costs of energy services lead to higher levels of energy consumption. By controlling financial motivations for reducing energy consumption, our study maintains parallels to engineering studies, but has the advantage of using actual observations of installation costs and energy use over multiple years. In addition, by introducing financial incentives as a treatment we are able to observe the relative effect of financial motivations to reduce energy use.

The effects of each of the efficiency treatments is measured in terms of changes in the quantity of natural gas consumed per residence, using data from three years prior to the treatment period as well as the two years in which the treatments were applied. The results indicate significant energy savings associated with the provision of financial incentives and attic insulation. At current prices, the reductions in natural gas consumption result in savings of between $125 and $175 per home per heating season.

To better understand the behavior contributing to changes in consumption, we also test for treatment effects on observed ambient indoor air temperatures of homes in our sample. The ambient indoor temperature data reveal that the financial incentives result in a significant reduction in temperature, while other treatments, as expected, do not have an impact. Finally, we analyze electricity consumption data for each household to test for potential spillover effects that may occur if households substitute one energy input for another. The results show that, if anything, measures targeting reductions in natural gas consumption may actually serve to reduce electricity consumption.

As with most field experiments, the size and composition of the sample we analyze is relatively limited and cannot be generalized to all single-family homes. The study does, however, make two important contributions. First, the results show that well-implemented efficiency measures can significantly reduce energy consumption. While there are tradeoffs in the cost and duration of implementing physical changes, such as attic insulation, as opposed to incentive-based changes, both types of measures are shown to effectively reduce residential energy use. The second main contribution of the research is the template that it provides for future studies evaluating the efficacy of energy efficiency and conservation measures. Given the increasing volume of funding allocated toward such programs and the challenges associated with measuring their effects, we see controlled experiments as an essential component of future policy initiatives, which will enable policy makers and property owners to make more informed decisions related to energy efficiency expenditures.

2. Background

In this section we describe previous research assessing the returns to measures aimed at reducing residential energy use. Measuring the actual returns to energy efficiency and conservation measures using naturally occurring data is challenging for several reasons. First, decisions regarding the intensity of energy use are not made independently from the choice of energy-related technologies. As Dubin and McFadden (1984) pointed out some time ago, decisions regarding investments in energy technology and consumption of energy are likely made simultaneously. By ignoring unobservables that may influence both the choice of energy technology and the intensity of use, studies that empirically estimate differences in energy consumption across households as a function of installed technologies will be biased.

In related research, Metcalf and Hassett (1999) show that ignoring the selection effects associated with the addition of attic insulation leads to biased estimates of performance. The authors state that selection could lead to endogeneity in observed energy use if “energy-conscious households both consume less energy and are more likely to invest in conservation capital.” The authors use both instrumental variables and differencing of household fixed effects to deal with potential endogeneity issues in their study of the returns to attic insulation, which they find to be considerably lower than returns based on engineering estimates.

Another challenge associated with measuring the returns to energy efficiency measures is endogeneity that may result when residents choose rental units based on characteristics associated with the pricing of energy inputs or appliance characteristics. In the United States nearly 30% of residential housing units are rental properties and approximately 32% of rental units that depend on liquid heating fuel have the cost of the fuel included in the rental agreement (US Census AHS, 2009).[1]

Levinson and Niemann (2004) utilize the U.S. Energy Information Administration's Residential Energy Consumption Survey (RECS) to show that residents of apartments in which utilities are included in the monthly rent maintain ambient temperatures that are 2.82 degrees F higher than comparable apartments where residents pay utilities. The results are confounded, however, by the fact that residents that prefer warmer temperatures self select into apartments where utilities are included. Accounting for this potential selection, the observed difference in ambient temperature falls to less than 1 degree F. Selection into rental unit-types makes accounting for rebound effects (see Greening et al. (2000) for a review) more challenging and may also lead to biased estimates of the returns to energy efficiency measures if tenants select into apartments based on other energy-related characteristics of the unit such as the efficiency of appliances.

Gillingham et al. (2012) use billing data from California to show that split incentives faced by landlords and tenants of rental properties can lead to higher energy use both because landlords of housing units where tenants pay the utilities have little incentive to invest in energy efficiency and because tenants have

[1] Rental units are also significantly more likely to have occupants under the age of 25. According to the AHS, 13.3% of rental units have a head of household that is under 25, whereas only 1.7% of units that are owned by the resident have a head of household that is under 25.