



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Estimating Payback to Residential Energy Efficiency Measures: A Field Experiment

Jordan Suter
Department of Economics; Oberlin College

Rumi Shammin
Department of Environmental Studies; Oberlin College

*Selected Paper prepared for presentation at the Agricultural & Applied Economics
Association 2010 AAEA, CAES, & WAEA Joint Annual Meeting, Denver, Colorado,
July 25-27, 2010*

*Copyright 2010 by Suter and Shammin. All rights reserved. Readers may make verbatim
copies of this document for non-commercial purposes by any means, provided that this
copyright notice appears on all such copies.*

Abstract

Interest in energy efficiency has grown in recent years as a result of increasing energy prices and greater concern for the externalities generated by fossil fuel combustion. Although energy efficiency measures have the potential to generate win-win situations whereby households gain financial benefits from reduced energy costs and society benefits from the generation of fewer energy consumption related externalities, energy efficiency appears to suffer from underinvestment. One potential explanation for this underinvestment is the lack of information that households and landlords have regarding the savings associated with energy efficiency measures. In this paper we test three types of energy efficiency strategies in an experimental design that utilizes institutionally owned homes that are rented to college students. Using data on actual natural gas consumption during the heating season, our results indicate modest energy savings associated with the installation of attic insulation and the provision of financial incentives for conservation. These results are supported by observations of ambient temperature data, which show that households receiving incentives, on average, reduced the ambient air temperature by 1.5 degrees F.

1 Introduction

The high cost of energy, combined with the need to reduce greenhouse gas emissions and an interest in reducing dependence on foreign energy resources has made residential energy efficiency a top priority for policymakers. Homeowners, however, often choose not to install energy efficiency measures in part because the financial paybacks associated with the retrofits are often very difficult to predict ex ante (Gillingham, Newell, and Palmer 2009). As a result, the number of installed efficiency measures is likely well below that which could be considered economically efficient. This paper seeks a better understanding of the relative payoffs from three energy efficiency strategies, thus providing information that would enable policy makers and property owners to make more efficient energy efficiency decisions. Accurate efficiency payback calculations are nearly impossible to do without the use of

controlled experiments and experiments such as this one will undoubtedly be a part of future research programs as larger scale efficiency programs are introduced.

The three efficiency strategies are tested using a field experiment involving 24 rental homes owned by Oberlin College in Oberlin, Ohio. Given that the residents of these homes do not pay utility bills, financial motivations for reducing energy use can presumably be controlled for, reducing the impact of rebound effects. Out of the set of 24 homes, four groups composed of six homes were randomly selected to receive the efficiency treatments. In one of the groups of homes, programmable thermostats were installed, an efficiency treatment that improves end-user control. The second group of residences had caulking and attic insulation installed, an efficiency strategy that is not dependent on user control. The third group of residences was provided financial incentives for energy conservation, an efficiency strategy that is strictly targeted at influencing behavior. The final group of six residences received no efficiency upgrades and therefore serves as a control group.

The costs of the efficiency improvements are calculated for the residences in each treatment group based on the actual costs of materials and insulation. The average cost of installing the programmable thermostats, including labor, was \$102 per residence, the average cost of the attic insulation and caulking was \$942 per residence, while the average realized cost of providing the financial incentives was \$191 per residence over the five month heating season. The cost savings of the efficiency improvements are measured in terms of changes in the quantity of natural gas used per residence relative to baseline levels over the course of the 2009 – 2010 heating season. In addition, we measure differences in ambient indoor air temperature across the 24 homes to get a better understanding of the inputs into the quantity of natural gas used.

Our results indicate significant energy savings associated with the provision of financial incentives and attic insulation, on the order 10% reductions in the quantity of natural gas consumed. The financial savings associated with this quantity of energy reduction depends critically on the price of natural gas. Assuming a conservative price of \$1.00 per hundred cubic feet (ccf) of natural gas, the 10% reduction works out to a financial savings of between \$120 and \$140 per residence associated with the insulation and financial incentives. These findings are complemented with the ambient temperature data, which show that the financial incentives result in a significant reduction in ambient air temperature, while other efficiency changes, as predicted, do not result in significantly different indoor air temperatures from the control.

The remainder of the paper is organized as follows. In the next section we outline the theory underlying the provision of the financial incentives and other efficiency measures. In the third section we describe the implementation of the efficiency measures and data collection. The fourth section describes the statistical analysis and key results, followed by some concluding thoughts in the final section.

2 Background and Theory

In this section we describe the motivation for the three efficiency treatments that we explore. Policies that improve the efficiency of residential housing units have the potential to generate win-win outcomes that both reduce expenditures on energy and reduce the negative externalities associated with fossil fuel consumption. Despite the potential benefits of energy efficiency improvements, households often fail to make adequate efficiency investments. Low levels of efficiency investments manifest themselves in terms of high implicit discount rates for energy efficient products (Hausman 1979). Excessive implicit

discount rates could be explained by information asymmetries which imply that efficiency improvements are not adequately capitalized into home prices (Jaffe and Stavins 1994). High implicit discount rates could also be due to uncertainty with respect to future energy prices and uncertainties regarding potential energy savings associated with available energy efficient technologies (Sutherland 1991).

Although households have been observed to underinvest in energy efficiency, a number of studies have shown that households are responsive to energy prices (Anderson and Newell 2004, Hassett and Metcalf 1995, Jaffe et al. 1995). At the same time, approximately 30% of all rental housing units include the payment of utilities in the rental agreement (Levinson and Niemann 2004). Residents of these units face no financial incentive to reduce their energy consumption either through investing in energy efficient technology or through engaging in behavior that would reduce the intensity of their energy use (e.g., choosing a lower thermostat setting).

The experimental treatments that we implement explore three different ways in which landlords could motivate reductions in energy use. The installation of a programmable thermostat gives residents a greater ability to accurately control heating levels. If residents are not able to continuously adjust heating levels to desired temperatures, then the ability to program the thermostat may potentially reduce household consumption. For example, homes with multiple residents may set the thermostat to the minimum temperature required for the comfort of the most cold intolerant household member, and maintain that temperature over the course of the day. Although residents may prefer slightly cooler temperatures for sleeping or when no one is at home, the time cost associated with making these small adjustments may exceed any potential benefits. By installing a programmable thermostat, the household is able to confer on a strategy for setting temperatures over the

course of the day that recognizes these consistent preferences for different temperatures at particular times of the day.

The motivation for installing additional insulation is clear. A landlord interested in reducing the cost of energy delivered faces a very basic tradeoff between the fixed, one-time cost of installing the insulation and the benefits that accrue over time from the reduced expenditures. This decision, however, requires accurate information with respect to both future energy prices and the quantity of energy reductions that will be achieved upon installation of the technology. This study attempts to provide more information with respect to the latter source of uncertainty.

Given the observation that households are responsive to energy prices, the third efficiency policy that we investigate in this research is the provision of financial incentives. Levinson and Niemann (2004) utilize the Department of Energy's Residential Energy Consumption Survey 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. These results, however, are confounded by the fact that residents that prefer warmer temperatures likely self select into apartments where utilities are included. Accounting for this potential selection, the observed difference in ambient temperature falls to less than one degree F. Using these results, they estimate that metering a residence and charging for energy consumption is associated with a 1.7% reduction in energy costs.

In this study, explicitly charging residents for natural gas use is not feasible since rental agreements already include the provision of utilities. To understand the role of financial incentives in motivating reductions in energy use, we instead provide six households in our sample a cash incentive of \$75 for each of the five winter heating months

(November – March). If the household consumes less than a baseline level of energy, calculated as 100 ccf (approximately 40%) below the average energy consumption for that residence in a particular month over the past three years, then the residence retains the entire \$75. If the residence uses more than the baseline level of natural gas, then they are charged at a rate of \$0.50 per ccf, up to a maximum charge of \$75. Therefore if the household uses 50 or more ccfs of natural gas above the three year average for a particular month, then they receive no compensation for the month.

The behavioral effect associated with the provision of financial incentives is captured by the graphical presentation in Figures 1 – 3. Figure 1 illustrates the standard case where residents are charged for their utility use. In particular, residents are charged price P_1 for each unit of natural gas that they consume and have utility over the ambient temperature of their home (which is assumed to be directly related to the amount of natural gas the home consumes) and all other goods. Since it is through heated air and water that residents gain utility from the natural gas, it makes sense that the indifference curve is parabolic in shape. Beyond the minimum point of the indifference curve the household is fully satiated, and consuming additional natural gas becomes undesirable. Given the budget constraint and indifference curve presented, a utility maximizing resident will choose to consume E_1 units of natural gas and X_1 units of other goods.

Under the current college policy, residents are not billed for the natural gas that they consume. As such, the budget constraint is a horizontal line and the utility maximizing resident consumes the quantity of natural gas at the minimum point of the indifference curve (point E_0 in Figure 2).

Now, suppose that residents are subject to the financial incentive policy described above. Under this policy residents receive a lump sum payment (Y) each month and then

pay a price P_2 , where $P_2 < P_1$, for every unit of natural gas that they consume above the baseline level. In Figure 3, the new budget constraint (B_2) has an intercept which is Y units higher than the original budget constraint. It begins to slope downward at the kink point which is equal to the predetermined baseline. The negative slope continues up to the quantity labeled “max” in Figure 3. Utility maximizing residents will now optimally reduce their natural gas use to level E_2 . Since $P_2 < P_1$, this implies $E_1 < E_2 < E_0$. Under the policy where the college pays all utilities, the total cost to the college of providing natural gas is $P_1 * E_0$. When the college offers bonus payments for energy conservation, the total cost of providing natural gas plus the cost of the incentive program is $P_2 * (E_0 - E_2) + P_1 * E_2$, which is strictly less than $P_1 * E_0$. In addition, since $U_2 > U_1$, student residents prefer this policy over the policy where utilities are provided, but no incentives are offered for conservation.

3 Implementation

In this section we detail the implementation of the experimental design described above. 24 residences were selected for inclusion in the study from the stock of approximately 50 homes owned by Oberlin College. We began by excluding the approximately 20 residences that are primarily rented out to faculty and focus in this study exclusively on units rented to undergraduates. We narrowed the set of residences to 24 after excluding homes with insufficient historic energy use data or that were anomalous for having either an abnormally high number of residents (all of the homes included in study have either 3 or 4 residents). From the set of 24 homes selected for inclusion, the six homes chosen for each of the four treatments were determined using a randomization device. Note that residents live in the homes for at most one academic year and that each home is occupied by a new set of

students each year. All of the residents are undergraduate students in either their third or fourth year.

The programmable thermostats and insulation/caulking were installed in the residences receiving these treatments during the summer of 2009 while residents were not present in the homes. Residents in homes receiving programmable thermostats were provided with a tutorial on how to operate the devices in the fall of 2009, but were provided no further information about the study. Residents in homes receiving insulation and caulking were not informed of the changes made to the homes.

For the homes receiving financial incentives, each residence was presented with a baseline level of natural gas use for each of the winter heating months (Nov. – March), determined as 100 ccfs (hundred cubic feet) below the average monthly natural gas use for that residence over the last three years, as described above. If actual natural gas use for a month is at or below this baseline, then the household receives a payment of \$75. For every ccf of natural gas consumed above this baseline, \$0.50 is subtracted from the \$75. If residents use more than 150 ccfs above the baseline (50 ccfs more than the 3 year average), then they receive no compensation. Residents are informed of their natural gas consumption and any compensation that applies at the end of each month and all compensation earned was paid to residents in cash.

In terms of data collection, we were provided with monthly billing records for each of the homes in our sample. In most cases, these data are available beginning in the fall of 2006 and extend through March of 2010. From these data we calculate the average daily quantity of natural gas consumed by dividing the quantity of natural gas by the length of the billing period (billing periods are as short as 28 days or as long as 33 days).

In addition to the natural gas consumption data, temperature and humidity sensors were installed in each of the 24 homes and recorded data in 10 minute intervals for the academic year 2009 - 2010. In this paper we analyze the ambient temperature data for the months of November and December of 2009. Additional data will be available at the end of the 2010 academic year. Utilizing information on both the energy consumption in the homes and ambient indoor temperatures will provide clues as to both the energy outcomes of the efficiency improvements as well as any behavioral differences that may be contributing to the observed differences in energy consumption.

4 Analysis

In this section we describe the methods of data analysis that we utilize to measure the treatment effects and highlight the resulting estimates. The analysis of the natural gas and ambient temperature data proceeds in three steps. First, we utilize the natural gas consumption data to do a simple difference-in-differences analysis to compare average energy consumption across the efficiency treatments both prior to the efficiency strategies being implemented and after the strategies are put into place. By comparing the changes in energy use in the three treatment groups to the control group, we are able to get a first look at the degree to which the treatments themselves are responsible for any observed changes in energy consumption.

The second stage of the analysis involves the estimation of a more comprehensive econometric model that controls for changes in outdoor air temperature and household specific effects. The two-way fixed-effects regression model is specified as

$$y_{it} = \alpha R_{it} + \beta I_{it} + \delta F_{it} + HDD_t + \lambda_t + \gamma_i + \mu_{it}, \quad (1)$$

where y_{it} is the observed quantity of natural gas consumed per day by household i in month t , R_{it} , I_{it} , F_{it} are indicator variables that equal one if household i receives, respectively, the thermostat, insulation, or financial incentive treatment in month t and is zero otherwise. HDD_t is a time specific variable that measures the number of heating degree days in month t , and λ_t is a month specific fixed effect that accounts for all common time specific variation in energy use not picked up by the number of heating degree days. Finally, γ_i is a household specific fixed effect for each of the 24 homes in the sample. The remaining error term is assumed to be independently and normally distributed.

The final statistical analysis utilizes the ambient temperature data collected from each of the homes for the months on November and December. In addition to providing a simple graphical depiction of the treatment outcomes in Figure 4, we also estimate a simple difference of means test after aggregating the ambient temperature data to find household averages. This conservatively treats the expected time specific correlation and assumes that the only independent observations result from comparisons made between residences.

4.1 Results

The difference in difference analysis generally reveals that the insulation and incentive treatments lead to significant reductions in natural gas consumption compared to the control treatment. It is notable that the pre-treatment period mean quantity of natural gas consumed for the homes in the financial incentives treatment is significantly lower than homes receiving the other treatments. The samples drawn for each of the treatments were determined completely randomly, and this anomaly with respect to the lower natural gas consumption does not pose a major problem for the analysis that follows.

The control group of homes shows a decrease of 0.59 ccfs of natural gas between the pre-treatment and treatment period. This could be a result of climatic conditions in the

treatment compared to the pre-treatment period or other factors that are not accounted for strictly by focusing on the means. In comparison to the control group, the households receiving the programmable thermostats consumed 0.60 ccfs more natural gas, a strong indication that this treatment did not have the desired energy reduction outcome. The homes receiving the insulation treatment and the energy incentives did exhibit significant reductions in natural gas usage compared to the control group. The reduction was significantly larger in absolute terms for the homes receiving the insulation, although in percentage terms the reductions are nearly identical across the two treatments.

The two-way fixed-effect regression analysis mainly confirms the findings of the difference in differences analysis. After controlling for the fixed effects associated with the structures and the time period effects that are common across units, the insulation and financial incentive treatments have negative parameter estimates. Although the magnitude of the effects are slightly larger than that derived from the difference in difference analysis, the small sample size results in parameter estimates that are only significantly different from zero at the 85% level. In addition, although the parameter estimate for the financial incentives is larger than for insulation, the two are not significantly different. Pooling the two treatments generates a parameter estimate that is significantly different from zero and positive at conventional levels ($p < 0.07$).

While the objective of the efficiency treatments is to generate a reduction in the quantity of natural gas consumed by the households, it is also interesting to understand the mechanism by which this occurs. The furnace is the primary source of natural gas consumption in these homes. Although residents could also reduce their natural gas consumption through reducing hot water usage or by making sure to close doors and windows, the clearest way to reduce consumption is through turning down the thermostat.

The differences in ambient heating patterns are clearly illustrated in Figure 4. On average the homes receiving the financial incentives had observed ambient temperatures that were approximately 1.5 degrees F lower than the control treatment. This difference is especially pronounced in the early morning hours, when it appears that some of the households were contentious about manually turning down their thermostats. In comparison, the ambient air temperature in the homes receiving insulation was not significantly different from the control group, as expected. Finally, the homes receiving the thermostats consistently exhibit slightly higher temperatures than the control group, although this difference is not significant at conventional levels. These ambient temperature results also re-confirm the earlier analysis. The financial incentives effectively result in reductions in energy consumption and this difference arises in part from lower ambient air temperatures. Conversely, the programmable thermostats do not result in energy reductions and if anything induce higher ambient air temperatures in the homes in which they are installed.

5 Discussion

This article set out to investigate the relative payback of three energy efficiency strategies. In the discussion that follows, we begin with estimates of the magnitude of the observed energy savings in comparison to the costs associated with implementing the strategies. We then offer some concluding thoughts and ideas for future research.

To begin, it is clear from our analysis is that programmable thermostats on their own are not an effective tool for reducing energy consumption. Although residents were provided information on how to operate the devices, without a clear incentive for

programming the thermostats to a lower temperature the thermostats do not induce energy reductions.

In estimating the energy and financial savings associated with the insulation and financial incentive treatments, we focus on the parameter estimates from the two-way fixed-effects model. These point estimates account for potential differences that occur as a result of climatic patterns across years and also account for differences both between and within residences over time. According to these point estimates, the installation of attic insulation resulted in a reduction of -0.80 ccf of natural gas per day, while the financial incentives result in -0.92 ccf per day. Aggregated across the five months of the heating season, this translates to a reduction of approximately 119 ccf for attic insulation and 138 ccf for the financial incentives. The financial savings associated with these reductions in natural gas consumption critically depend on the price of natural gas. In 2009 Oberlin College paid an average variable cost of just over one dollar per ccf of natural gas supplied to the homes in the sample. Assuming conservatively that this price of one dollar persists, the financial savings associated with the insulation and financial savings are equivalent to \$119 and \$138 respectively. Given that the average realized cost of the financial incentives came out to be \$191 across the six homes, the net benefits of this strategy were likely negative for the 2009 – 2010 heating season. Given the lack of precision of our estimates, however, the net benefits are not significantly different from zero. Assuming that the point estimate is estimated precisely, a price greater than \$1.44 per ccf of natural gas would result in positive net benefits. The rather large fluctuations observed in energy markets over the last five years suggest that this price is well within the range of possibilities. Residential prices peaked in early 2008 at over \$2.00 per ccf.

Measuring the payback associated with the installation of attic insulation is slightly more complex given the durability of the technology. The cost per house for the insulation treatment ranged from a low of \$704 to a high of \$1,224, with a mean of \$942. Conservatively assuming constant prices of one dollar per ccf, a discount rate of five percent, and a duration of 20 years for the insulation, the net benefits associated with the insulation is approximately \$1,600 per residence and full payback occurs in approximately eight and a half years. A nice feature of this experiment setup is that we will continue to be able to track the actual payback from year to year, through between residence comparisons.

Overall, our results suggest modest efficiency gains associated with the installation of attic insulation and the provision of financial incentives. Although financial incentives appear to induce slightly greater reductions in energy use, they are more costly on an annualized basis. Further research on the optimal structure of the incentive program is essential if institutions and landlords have an interest in reducing energy use through such programs. The treatment effects that we observe come from only one heating season, and we plan to continue to test their robustness with data from future heating seasons. In addition, interaction effects between the treatments are also likely to have a significant impact on observed energy use. For example, although the programmable thermostats on their own do not appear to be particularly effective in reducing energy consumption, when coupled with the financial incentives this may provide the control necessary for households to manage their energy conservation to a greater degree.

References

- Anderson, S., R. Newell R. 2004. Information programs for technology adoption: the case of energy-efficiency audits. *Resource and Energy Economics* 26. 27–50.
- Bohi, D., M. Zimmerman 1984. An update on econometric studies of energy demand behavior. *Annual Review of Energy* 9. 105–54.
- Gillingham K, R Newell, K. Palmer. 2009. Energy efficiency and policy. Resources for the Future. Discussion Paper 09-13. Washington, DC.
- Hassett, K. G. Metcalf. 1995. Energy tax credits and residential conservation investment: evidence from panel data. *Journal of Public Economics*. 57. 201-217.
- Hassett, K. G. Metcalf. 1999. Measuring the energy savings from home improvement investments: evidence from monthly billing data. *Review of Economics and Statistics*. 81. 516-528.
- Hausman, J. 1979. Individual discount rates and the purchase and utilization of energy-using durables. *The Bell Journal of Economics* 10: 33–54
- Jaffe A, Stavins R. 1994. The Energy Efficiency Gap: What Does It Mean? *Energy Policy* 22: 804–10.
- Jaffe A, Stavins R, Newell R. 1995. Dynamic incentives of environmental regulations: the effects of alternative policy instruments on technology diffusion. *Journal of Environmental Economics and Management* 29. 243–263.
- Levinson, A., S. Niemann. 2004. Energy use by apartment tenants when landlords pay for utilities. *Resource and Energy Economics*. 26. 51-75.
- Sutherland, RJ. 1991. Market Barriers to Energy Efficiency Investments. *The Energy Journal* 12. 15–34.

Figures and Tables

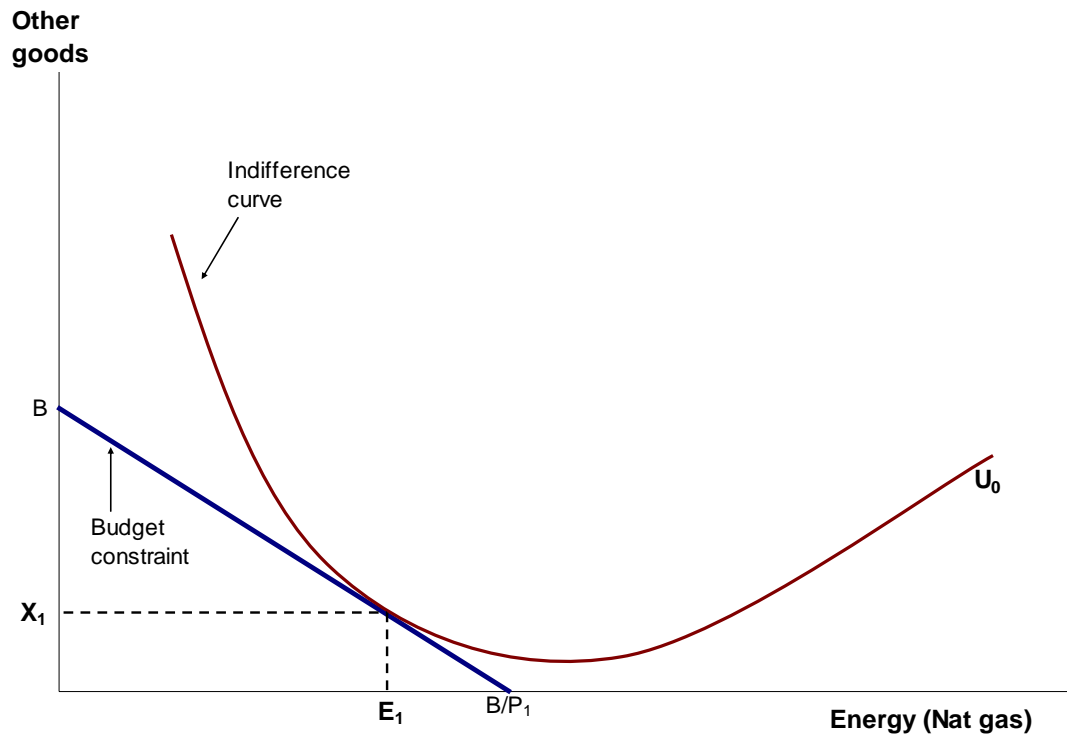


Figure 1: Residents billed for natural gas consumption at price P_1

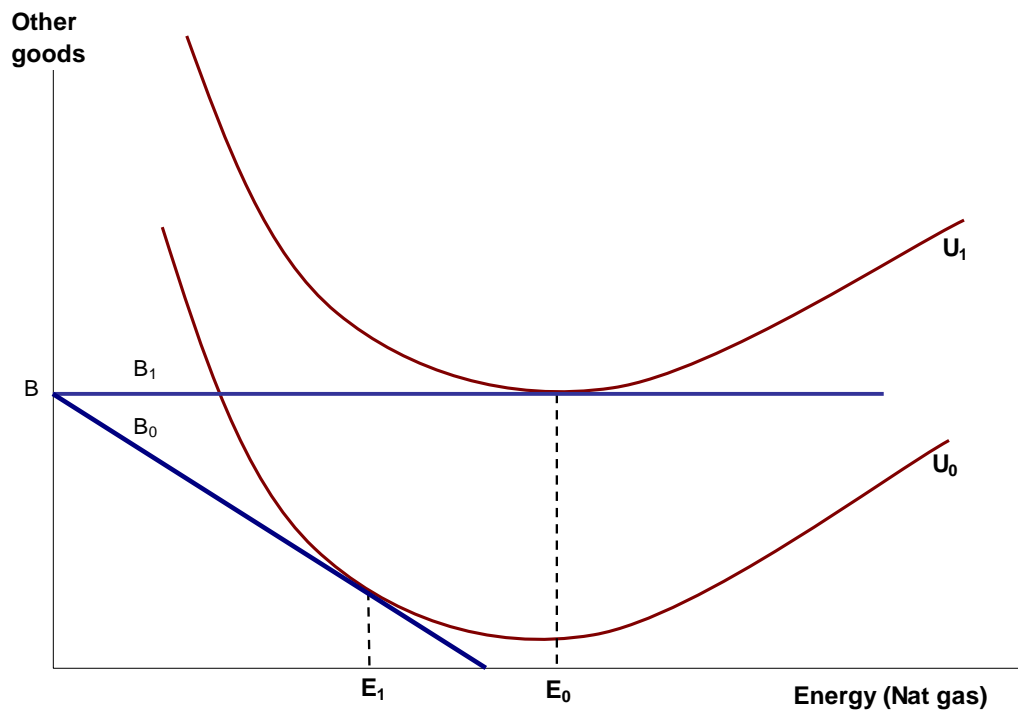


Figure 2: Residents do not pay for their natural gas consumption.

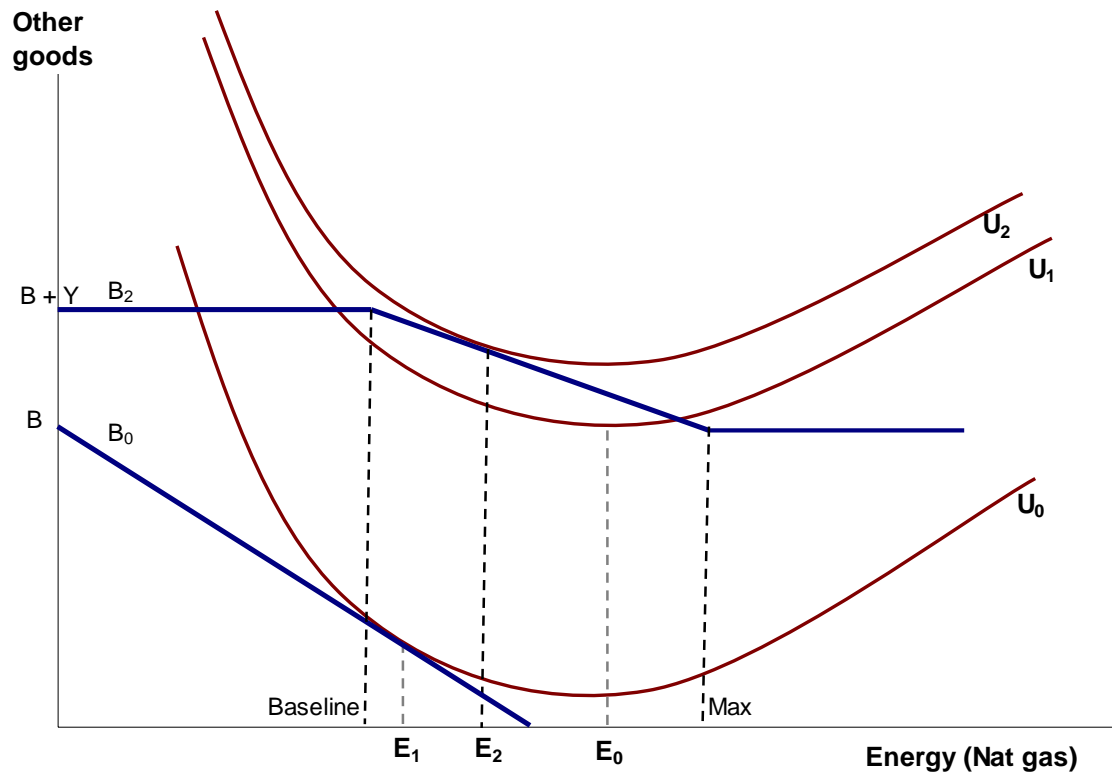


Figure 3: Residents receive financial incentives.

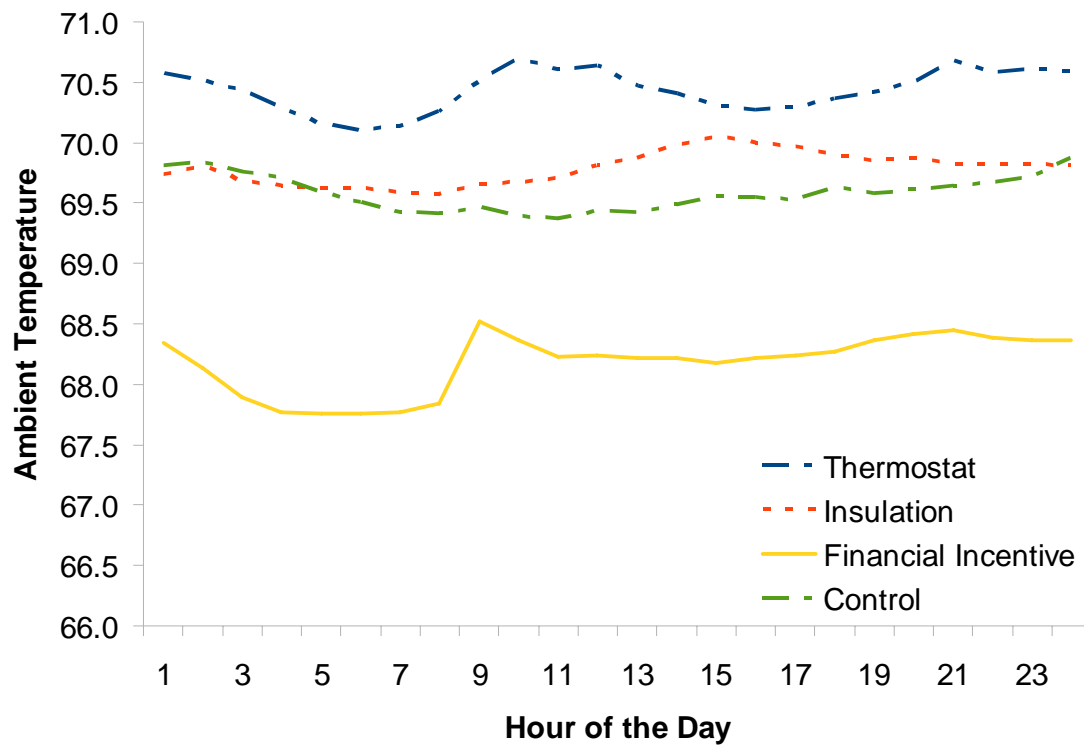


Figure 4: Treatment effects on observed ambient temperature (November – December)

Table 1: Difference in differences analysis

Treatment	Pre-treatment [10/06 -3/09]		Post-treatment: [10/09 – 3/10]		Difference	Diff-in-Diff
	Mean (ccf/day)	SE	Mean (ccf/day)	SE		
Control	9.63	1.63	9.03	1.47	-0.59	-
Thermostat	9.18	0.96	9.19	1.19	0.01	0.60
Insulation	9.22	0.66	7.93	0.73	-1.29	-0.70
Incentive	7.21	0.66	6.23	0.75	-0.98	-0.39

Table 2: Two-way fixed-effects regression

Variable	Coefficient	SE	t-value
HDD	0.010***	0.001	19.93
Thermostat	0.086	0.497	0.17
Insulation	-0.795	0.497	-1.60
Incentive	-0.919*	0.521	-1.76
Time dummies	***		
Residence dummies	***		
R ²	0.93		
Observations	750		

Table 3: Test of treatment means from ambient temperature (Nov – Dec)

Treatment	Mean	SE	Diff from control	T-value
Control	69.58	0.66	-	-
Thermostat	70.43	0.64	0.85	1.30
Insulation	69.78	0.72	0.20	0.29
Incentive	68.18	0.53	-1.40***	-2.37