Split Incentives in Residential Energy Consumption

Kenneth Gillingham, Matthew Harding, and David Rapson

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Kenneth Gillingham
Yale University
School of Forestry & Environmental Studies
195 Prospect Street
New Haven, CT 06511
Phone: (650) 353-6578
Email: kenneth.gillingham@yale.edu

Matthew Harding
Stanford University
Department of Economics
579 Serra Mall
Stanford, CA 94305
Phone: (650) 723-4116
Fax: (650) 725-5702
Email: mch@stanford.edu

David Rapson
University of California, Davis
Department of Economics
One Shields Ave
Davis, CA 95616
Phone: (530) 752-5368
Email: dsrapson@ucdavis.edu

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We explore two split incentive issues between owners and occupants of residential dwellings: heating or cooling incentives are suboptimal when the occupant does not pay for energy use, and insulation incentives are suboptimal when the occupant cannot perfectly observe the owner's insulation choice. We empirically quantify the effect of these two market failures and how they affect behavior in California. We find that those who pay are 16 percent more likely to change the heating setting at night and owner-occupied dwellings are 20 percent more likely to be insulated in the attic or ceiling. However, in contrast to common conception, we find that only small overall energy savings may be possible from policy interventions aimed at correcting the split incentive issues.

JEL: Q4,Q5

Keywords: principal-agent; asymmetric information; CO_2 emissions.

1. Introduction

It is often claimed that differing incentives between owners and occupants of residential dwellings lead to the over-consumption of energy. For example, the New York Times recently quoted building managers in New York estimating that apartments that do not pay for electricity "expend at least 30 percent more electricity year-round than their counterparts" and suggested that this came with a "considerable environmental cost" (New York Times 2010). The concern here is that apartment occupants face a zero marginal cost for the energy used to provide cooling. An identical split incentive issue may occur when occupants do not pay for heat. Differing incentives may also occur when a prospective occupant imperfectly observes the owner's choice of energy efficiency of the dwelling, reducing the owner's incentive to properly insulate the dwelling. These issues of differing incentives are principal-agent problems that have the potential to lead to inefficient allocation of resources. In the policy realm, these potential market failures are often used to justify energy efficiency standards or other regulatory actions. With residential buildings making up just over 20 percent of 2006 primary energy demand in the United States, and with over a third of all occupied housing units being rental units, the amount of energy consumption affected by these misaligned incentives might reasonably be expected to be substantial (EIA 2008, US Census Bureau 2010). Yet, to date, our understanding of these split incentive issues in residential energy consumption is remarkably limited.

We provide empirical evidence quantifying the magnitude of split incentives issues in California. First, we find evidence of a heating or cooling split incentive issue when the occupant does not pay for heating or cooling. For example, households that pay for heating are 16 percent more likely to change the heating setting at night. Second, we find evidence of an insulation split incentive issue due to asymmetric information in the contracting process between the owner and prospective occupant. We find that owner-occupied dwellings where the resident pays for heating and cooling are 20 percent more likely to be insulated in the attic or ceiling and 13 percent more likely to be insulated in the exterior walls.

There is a long history of economic theory developed to explain a variety of situations where two parties have differing incentives, usually occurring in settings where there is asymmetric information between a principal and an agent either before or after the contracting phase (e.g., Arrow (1963), Spence and Zeckhauser (1971), Alchian and Demsetz (1972), Jensen and Meckling (1976), Grossman and Hart (1982), Laffont and Martimort (2001)). The possibility of split incentives between owners and occupants of residential dwellings was first described with case studies indicating a "landlord-tenant" issue of asymmetric information leading to less insulation and less energy efficient appliances than might otherwise be expected (Blumstein, Krieg, Schipper, and York 1980). Since then, split incentives between owners and occupants have been qualitatively discussed in a variety of studies elucidating the potential market failures that may impede investments in improving residential energy efficiency (Fisher and Rothkopf 1989, Jaffe and Stavins 1994, Nadel 2002, Gillingham, Newell, and Palmer 2006, Gillingham, Newell, and Palmer 2009).

Murtishaw and Sathaye (2006) provide quantitative estimates of the potential importance of principal-agent problems between landlords and tenants in several areas of residential energy use. Specifically, they examine the number of dwellings that may be affected by split incentive issues in at least one type of energy use, and use this number to calculate a theoretical upper bound of energy savings possible if policies could be implemented to entirely address these issues. They find that 35 percent of residential energy use may be affected by at least one split incentive problem, suggesting that the issue may be a large one. A report by the International Energy Agency (2007) looks at case studies of situations where split incentives appear to be very important. Both of these studies discuss the differing ways that split incentives may occur in energy consumption, but neither provides empirical evidence of the extent to which the different types of problems may exist.

Levinson and Niemann (2004) provide empirical evidence for a principal-agent problem when landlords pay for heat. Levinson and Niemann use the US Department of Energy's Residential Energy Consumption Survey (RECS) to note that when heat is included in the rent, the average winter indoor temperature is higher than when the heat is not included. Davis (2009) empirically examines the possibility of a principal-agent problem in the purchase of energy efficient appliances by landlords when occupants pay the electricity bill. Davis finds that after controlling for household covariates, landlords who do not pay the electricity bill are less likely to have purchased "Energy Star" appliances.[1]

We find only limited empirical evidence for a split incentive issue in the *level* of temperature setting for heating or cooling, and posit that these findings may be partly related to heterogeneity in preferences for heat at different times of day. However, we find stronger evidence that split incentives can affect behavior by influencing when occupants *change* their temperature setting. Those who do not pay for heating or cooling are less likely to change the setting. We also find statistically significant evidence that owner-occupied dwellings where the owner pays for heat are more likely to be insulated. Using these empirical results, we perform a back-of-the-envelope calculation, which indicates that while split incentive issues may change household behavior, the resulting energy and carbon dioxide savings from fully correcting for these issues would be moderate, with greater savings coming from the insulation split incentive issue. This result can be explained by

[1]To achieve the Energy Star designation from the U.S. Environmental Protection Agency, an appliance must meet a stringent standard for energy efficiency.

the small number of households who do not pay for heat *and* the moderate behavioral changes we find for both insulation and heating or cooling. An implication of these results is that while certain low-cost policies may improve economic efficiency by addressing market failures from split incentive issues, addressing these issues would not dramatically change energy use or even be significant step toward meeting California's obligations under the Global Warming Solutions Act of 2006 (Assembly Bill 32).

This paper is structured as follows. In the next section, we provide a conceptual framework to help formalize when and how split incentives in the owner-occupant relationship may lead to an overconsumption of energy. This framework provides the hypotheses to be tested in our empirical analysis. The third section describes our dataset. The fourth section quantifies each aspect of the split incentive problem, reporting our empirical results for heating, cooling, and insulation. The next section describes the results of our back-of-the-envelope calculations, quantifying a rough upper bound for the energy savings that policies to address these split incentive issues could achieve. The final section concludes with a discussion of implications for energy efficiency policy.

2. Conceptual Framework

Split incentives can occur when the dwelling is either owned or rented, depending on whether the occupant pays the energy bill. This section presents a conceptual framework for the split incentive issues we will investigate empirically in the later sections.[2] Figure 1 indicates three possible avenues for split incentives to play a role.

[Figure 1 about here]

[2]We also mathematically formalize this conceptual framework in a contract theory model of the principal-agent problems. This model is available on the authors' websites or upon request.

In the upper left box (1), the dwelling is owner-occupied and the occupant pays for energy use. There are no split incentive concerns here.[3] In the lower right (labeled (4)), the occupant is a renter and does not pay for at least some part of their energy use, such as heating, central cooling, or even electricity. In this case, the occupant faces a zero marginal cost for energy use and thus has little incentive to pay attention to the amount of energy used, which can be thought of as a principal-agent problem where the owner is a principal and tenant is an agent. This may lead to greater use of heating or cooling, less effort exerted to change heating or cooling settings (e.g., turning heating down at night), or fewer purchases of energy-efficient appliances.[4] Since the owner is paying for energy use and also making the choice of the level of insulation and energy efficiency of appliances, the owner's incentives to invest in efficiency are theoretically ambiguous. There are two effects that work in opposite directions. If the owner expects the occupant to over-consume energy, then the owner may over-invest in insulation to compensate. On the other hand, if the owner is unable to fully capitalize investment in efficiency into the rent or property resale value, the owner may choose to under-invest in efficiency.

The upper right box (2) shows a situation where the occupant is a renter who pays for all of his or her energy use, but may not be able to perfectly observe previous choices made by the owner that affect the energy efficiency of the dwelling. In this case, the owner has little incentive to insulate the dwelling or to install energy-efficient appliances (e.g., refrigerators, washers & dryers). Here there is a principal-agent problem where the owner is the agent who makes a (partly) hidden action. Davis (2009) finds empirical evidence for this particular issue in the context of energy-efficient appliances. Since the occupant pays for the energy use, the occupant has an incentive to pay

[3]This presumes that home improvements are fully capitalized – or at least that consumers consider this to be the case.
[4]Levinson and Niemann (2004) provide empirical evidence for a greater use of heating in this particular situation, but do no consider the insulation decision.

attention to the use of energy, and thus there is less likely to be a principal-agent problem relating to the effort to reduce energy use from the existing stock of durable goods in the household.[5]

In the bottom left (box (3)), the dwelling is owner-occupied, but for some reason, the occupant does not pay for at least some part of the energy use. This is most likely to occur for townhouses and other attached housing complexes. Since the occupant does not pay for his or her entire energy use, he or she may keep the heating set higher and cooling set lower, and may make fewer purchases of energy-efficient appliances (as in box (4)). In addition, there may be a split incentive issue where the third-party provider of the energy is the agent in the principal-agent problem, as in box (2). This issue would only occur if the occupant is responsible for the choice of insulation and the energy efficiency of the appliances but does not pay for the energy use. While this may occur in some settings, often in attached housing complexes where the owner-occupiers do not pay for their energy use, in most cases there are guidelines determining the amount of insulation required. In addition, it is possible for the payer of the energy bill to install additional insulation or energy-efficient appliances themselves. Thus, the split incentive issue may be internalized through creative contracts. Hence, we include "under-insulation and less efficient appliances" in brackets in Figure 1.

2.1. **Testable implications.** The framework developed above provides several testable implications for our empirical analysis:

- We expect occupants who rent their dwellings and pay for heating or cooling to reside in under-insulated dwellings relative to those who rent and do not pay for heating or cooling (box (2) in Figure 1).

[5]A principal-agent problem could still occur for energy-efficient investments by the occupant if the investment has a longer lifespan than the expected length of the lease.

- We expect occupants who do not pay for their heating or cooling to put in less effort to reduce their heating and cooling use relative to those who pay for their heating or cooling (boxes (3) and (4) in Figure 1). This can come about through changing heating or cooling settings more often, higher temperatures when heating, and lower temperatures when cooling. This is also expected regardless of whether the tenant owns or rents the dwelling.
- We expect occupants who own their dwelling and do not pay for their heating or cooling to under-insulate their dwelling relative to those who own and pay for their heating or cooling (box (3) in Figure 1).

3. Data

3.1. **Data sources.** Our dataset is from the California Statewide Residential Appliance Saturation Study (RASS), which was administered by the California Energy Commission. The study surveys households in California to assess the determinants of the saturation of different appliances in order to inform the utility planning process. The survey was performed in 2003, and involved first sending out mail surveys to 100,000 single-metered homes randomly chosen throughout California. After two rounds of mail surveys, 18,970 responses were received. To address possible participation bias, a sample of 2,183 of the non-respondents were contacted, either through a third mail survey with an incentive, a telephone interview, or an in-person interview.[6] In addition, there was a separate process for master-metered customers. In a first stage, 616 telephone surveys were conducted with the manager of the master-metered facility. Following this, mail surveys were sent to the individual customers within each of the master-metered facilities, with a follow-up phone interview to raise response rates. Of the 5,593 surveys sent out, 767 were completed and returned.

[6]The characteristics of the non-respondents do not appear to differ appreciably from those who first responded.

After combining these data, the end result is a dataset of 20,933 responses designed to be representative of California households in terms of geography, income, housing type, and other key characteristics.[7]

While the California Energy Commission took significant steps to ensure unbiased participation across the different demographic groups, some participation issues could not be eliminated. Extremely low and extremely high users of electricity did not participate in the surveys. There also appears to be some under-reporting by the hispanic population in part due to undocumented residents. The overall participation rate, while relatively low, is consistent with other recent California surveys.

We augmented the RASS dataset with 2003 electricity price data from each electric utility. The data were matched based on the annual kilowatt-hour (kWh) electricity consumption and utility climate zone of the electricity customer. California has a "tiered-rate" electricity price schedule, whereby consumers pay a low rate for consumption below a certain amount, a higher rate for the next increment of consumption, and so on.[8] The annual kWh consumption variable in the RASS dataset allows us to place each observation on the electricity price tier they are most likely on – so each household is matched with the most likely marginal price they face.

We recognize that this electricity price variable has limitations in an analysis of consumer behavior, for there is some evidence that consumers do not realize what tier they are on, and thus what marginal price of electricity they are being charged. For example, we cannot rule out that consumers may make decisions based on the average price of electricity (Borenstein 2009, Ito 2010). Moreover, RASS only contains the annual kWh electricity consumption, but consumers may be

[7]In cleaning the dataset, we dropped a small number of observations that were coded as living in mobile homes or "other" dwellings, or had more than 10 children.

[8]See Borenstein (2008) and Borenstein (2009) for further details of California's tiered electricity pricing schedule.

on different tiers at different months of the year. Finally, some electricity customers receive lower rates if they are low income customers or have medical conditions and we do not observe these particular situations. Fortunately, we find our results are completely insensitive to the inclusion or exclusion of the electricity price variable.

3.2. **Summary statistics.** The key variables from the RASS dataset used in this study include a variety of housing characteristics, demographics, and, most importantly, owner and occupant choices that may be affected by principal-agent problems. Summary statistics for these variables in our full final cleaned dataset are given in Table 1.

[Table 1 about here]

The reported heating and cooling settings at different times of day (i.e., morning, day, evening, and night) are two of our primary variables of interest that help us identify a heating or cooling split incentive issue. These take values from one to six. For the heating variables, these correspond having heat below 55°F, $56-60$°F, $61-65$°F, $66-70$°F, $71-75$°F, and over 75°F. For the central cooling variables, these categories correspond to having the temperature below 70°F, $70-73$°F, $74-76$°F, $77-80$°F, and over 80°F.

The RASS dataset also includes two variables capturing the degree to which the dwelling is insulated. One variable of interest is an indicator variable for whether the attic/ceiling of the dwelling is insulated at all. The second variable of interest is an indicator variable for whether at least some of the exterior walls of the dwelling are insulated.[9]

We take a separate subsample of our final cleaned dataset for our heating and cooling results. Specifically, we recognize that heating costs are not likely to be a major concern for large areas

[9]This variable is created from a categorical variable taking a value one for "yes, all", two for "yes, some", and three for "no." An alternative coding of one if "yes, all" and zero otherwise gives similar results.

of Southern California that rarely use much heating, so we take a subsample where we include all observations with greater than 2,000 $65°$F heating degree days (HDD65), where HDD65 are defined as the difference between the average temperature in that day and $65°$F summed over all days of the year that are cooler than $65°$F.[10] By focusing on consumers in cooler climates, we can examine behavioral responses from those consumers for whom we would expect heating bills to be significant. This heating subsample consists of 10,453 observations. For this subsample, Table 2 (top) gives a cross-tabulation for the number of observations that fall into the categories described in Figure 1. This cross-tabulation indicates that much of the sampled population (76 percent) falls into box (1) in Figure 1, where there are no split incentive issues. The cross-tabulation also shows that a reasonable number of the observations fall within categories where there are split incentive issues, and in particular box (2), where we would expect to find under-insulation (22 percent).

[Table 2 about here]

Similarly, cooling costs are not likely to be a major concern for much of Northern California. Thus, we take a subsample in which we include all observations with greater than 1,000 $65°$F cooling degree days (CDD65), where CDD65 are defined as the difference between the average temperature in that day and $65°$F summed over all days of the year that are warmer than $65°$F. We consider this subsample much more likely to capture the behavioral responses from those consumers for whom we would expect cooling bills to be significant. This cooling subsample consists of 8,800 observations. The bottom half of Table 2 gives a cross-tabulation for the number of observations that use central cooling and fall into the categories described in Figure 1. We focus on central cooling, rather than room air conditioning, due to the data availability for central cooling and the greater ability to control the temperature in centrally cooled dwellings. Just as for heating,

[10]The choice of 2,000 HDD65 is somewhat arbitrary, but the results do not appear to change appreciably with reasonable changes to this assumption.

the cross-tabulation shows that much of the sampled population (57 percent) is not subject to split incentive issues, for it falls into box (1) in Figure 1. However, over 30 percent do not pay for cooling, and thus may have split incentives leading to less effort to reduce cooling use (boxes (3) and (4)). Since insulation is an important factor for energy use in both hot and cold climates, we use the combined sample when analyzing the insulation choice.

4. Estimation of Household Behavior

The conceptual framework in Section 2 suggested several hypotheses that can be tested in our data. We begin by discussing the estimation of whether homeowners invest effort in order to save energy, the split incentive issue indicated in boxes (3) and (4) in Figure 1. An attractive feature of our dataset for this purpose is that we observe the heating and cooling settings in the home at different times of the day. As discussed in the previous section, the temperature settings are defined as ordered choices that fall into six distinct bins corresponding to the temperature interval.[11]

To begin, we ask: are households that do not pay for heat more likely to have a higher heating setting? Consider a model for heating choices, $H_{j,t} = \{1, 2, 3, 4, 5, 6\}$ for household j in period $t = \{morning, day, evening, night\}$. Let $H^*_{j,t}$ be a continuous latent variable denoting the optimal setting:

$$H^*_{j,t} = \alpha_t + \beta_t Pay_j + \gamma_t Own_j + \sum_c \delta_{t,c} C_{j,c} + \sum_d \eta_{t,d} D_{j,d} + u_{j,t}. \tag{1}$$

We thus model the optimal temperature setting decision as a function of whether the household pays for heating (Pay_j) or owns the dwelling (Own_j), as well as a variety of dwelling characteristics (C). The most important dwelling characteristics are the quantity of insulation, the price and

[11]It is tempting to model this variable as interval-coded data, but we are concerned that the surveyed households may have interpreted the categories loosely when filling out the survey – thus interpreting the variable as a series of ordered choices appears more reasonable.

type of heating, the heating degree days, the geographic location of the home, the size of the living space, and the availability of a programmable thermostat. Additionally, we model the decision as also depending on household characteristics (D) such as income, number of children and elderly residents, and education levels. The error term $u_{j,t}$ is assumed to be Normally distributed.

Furthermore, let us assume that there is a sequence of cut-off points $\tau_0, \tau_1, \tau_2, \ldots$ such that intervals on $H^*_{j,t}$ map into the reported approximations of heating settings throughout the day in a monotonic fashion. Thus, for example, a report of $H_{j,t} = 2$, or "$56 - 60$°F," corresponds to the latent heating choice greater than τ_0 but less than τ_1. The cut-off points are known to the household but not observed by the econometrician. Under the Normality assumption on the error distribution, the probability of observing a report of "$56 - 60$°F" for household j in period t corresponds to the probability:

$$Pr(\tau_0 < H^*_{j,t} < \tau_1) = \Phi(\tau_1 - \nu_{j,t}) - \Phi(\tau_0 - \nu_{j,t}), \tag{2}$$

where $\nu_{j,t} = \alpha_t + \beta_t Pay_j + \gamma_t Own_j + \sum_c \delta_{t,c} C_{j,c} + \sum_d \eta_{t,d} D_{j,d}$, and $\Phi(\cdot)$ denotes the standard Normal cdf. The unknown parameters of the model (including the cut-off points) can thus be estimated by maximum likelihood as an ordered probit model. For ease of interpretation, we are interested in the estimated marginal effects evaluated at the mean.

The marginal effect of a change in some dwelling attribute C_c on a given heating setting s is given by:

$$\frac{\partial Pr(H_t = s)}{\partial C_c} = \delta_{t,c}(\phi(\tau_s - \bar{\nu}_t) - \phi(\tau_{s-1} - \bar{\nu}_t)), \tag{3}$$

which we evaluate at the mean values of the covariates $\bar{\nu}_t$, and $\phi(\cdot)$ denotes the standard Normal pdf. The marginal effect with respect to all of the other covariates are defined similarly. An analogous specification can be assumed for central cooling.

While this empirical model is easy to estimate and represents a convenient reduced form specification for the choice of a heating setting, the parameters of interest are only identified with our cross-sectional data if we believe that our controls entirely capture household-level heterogeneity that may be correlated with whether or not the household pays for heating. Our rich set of covariate controls may well be sufficient. However, all but a small percentage of households pay for their heating (three percent of the heating subsample), so a relatively small number of households will be identifying the coefficients in each of the heating setting bins.

These factors suggest that in addition to examining the level of the temperature setting, it may also be worthwhile to examine other features of the data that also imply a split incentive issue. Section 2 suggests that rational individuals who pay for their heat would *change* their temperature settings during the day to reduce energy use during times of lower heating needs. For example, a household looking to save energy may consider reducing or switching off the heating during the day when they are at work, even if they have a strong preference for warmth when they are at home. The ordered temperature settings in the RASS dataset are well-suited to this type of analysis. In this case, we only must believe that households choose a living arrangement (i.e., whether to live in a place where heat is paid for) based on larger factors and not on the effort cost of changing the thermostat. This appears very plausible.

We define an indicator variable Y_j which equals 1 if the household changes the heating settings during the day, thereby exhibiting effort to reduce energy use. We then posit the following probit model:

$$Pr(Y_j = 1) = \Phi\left(\alpha + \beta Pay_j + \gamma Own_j + \sum_c \delta_c C_{j,c} + \sum_d \eta_d D_{j,d}\right). \tag{4}$$

We assume that the above equation corresponds to the reduced form of the optimal decision of whether to change the heating setting. We report the estimated marginal effects $\frac{\partial Pr(Y=1)}{\partial C_c} = \delta_c \phi(\bar{\nu})$, where $\bar{\nu}$ corresponds to $\alpha + \beta Pay_j + \gamma Own_j + \sum_c \delta_c C_{j,c} + \sum_d \eta_d D_{j,d}$ evaluated at the mean values.

Of course, whether or not a household changes the heating settings at all during the day is just one of several plausible empirical models of heating setting switching behavior. We also examine analogous models where the dependent variable equals one if the household changes the heating setting between morning and evening, evening and night or night and morning. Furthermore, we explore whether households set their heating warmer in the evening than at night and warmer in the morning than at night. We also examine a analogous specifications for central cooling to all of those described above.

Finally, we can examine the insulation split incentive issue using a similar probit model to (4). The dependent variable for the insulation regression is either an indicator variable for whether the walls are insulated or an indicator variable for whether the attic/ceiling is insulated. In these estimations we can explore the relationship between the presence of insulation and whether the home is owner-occupied, while controlling for a number of home characteristics and resident demographics. Throughout we report estimated marginal effects evaluated at the mean.

5. Empirical Results

5.1. **Heating and cooling.**

5.1.1. *Heating and cooling settings.* First let us investigate how the probability that a consumer is in any one of the heating or cooling setting bins changes if the consumer pays for their energy use. We would expect to find that households who pay for their energy use will attempt to save on their energy bill by lowering the level of heating in their home. Surprisingly, we find only limited support for this hypothesis.

[Table 3 about here]

Tables 3 presents marginal effects estimated from the ordered probit model for heating settings in the morning. The columns of the tables correspond to the different heating bins. One can interpret the results as changes in the probability of choosing a given temperature setting in response to a change in the covariates for the mean household. We find extremely similar results for other times of day, although with more significance in other bins and less in the below $55°$F bin. However, the signs and the general magnitude of the coefficients are similar. The central cooling results are also similar but with slightly less statistical significance.

These findings suggest that households who pay for heat are more likely to select lower heating settings below $65°$F. The results for the other categories display the sign we would expect, but are for the most part not statistically significant. One possible explanation for not finding a stronger relationship is that the energy bill is just not very salient in consumer decision-making. We view this as possible, but less likely given the statistically significant results in Levinson and Niemann (2004). Alternatively, these results can be viewed as attesting to the importance of heterogeneity in preferences over heating levels, a possible endogeneity concern that we cannot control or instrument for. This provides motivation for the *changes* specification in the next section.

Several of the other coefficients point to the most important factors determining the heating setting – many of which appear to dominate paying for heat in importance. We find statistically significant evidence that households with larger houses or who live in colder climates choose lower heating settings both in the morning and at night. We interpret this as reflecting the difficulty of heating such homes to a higher degree, which may present both technological challenges as well as substantially higher costs. Similarly, we find that homes with more children and seniors are heated to a higher degree, reflecting the increased level of heating required for comfort in such homes.

5.1.2. *Changes in heating and cooling settings.* Our second estimation strategy focuses on whether households make *changes* to their heating or cooling settings during the day in response to economic incentives. This estimation strategy is less likely to suffer from unobserved heterogeneity since irrespective of the chosen level of heating it remains rational to make changes between different periods during the day. For example, one can save energy by turning down the heating during the day or at night.

Table 4 reports the estimated marginal effects. The columns of this table correspond to different dependent variables. Column 1 reports the results of a model where the dependent variable is an indicator for whether the household made *any* changes to the heating setting during the day. Columns 2, 3, and 5 analyze the cases where households choose different settings in the morning and evening, evening and night and night and morning respectively. Column 4 reports the results of a probit model where households choose a higher setting in the evening than at night, as would be expected. Column 6 reports the corresponding results when a household chooses a lower setting at night than in the morning.

[Table 4 about here]

These results indicate that households who pay for heating are more likely to make changes during the day, between evening and night, between night and morning. These results are both statistically and economically significant, suggesting that economic incentives can make a substantial difference in driving optimizing behavior during the day. For example, the results suggest that those who pay for heat are 16 percent more likely to change the heating setting at night. Columns

4 and 5 suggest that there is heterogeneity in the direction that households change the heating setting.

The propensity to make changes to the heating settings during the day varies with both physical home characteristics and demographics. The results indicate that households who own their homes and have programmable thermostats are more likely to make changes to their settings. On the other hand, households residing in apartment dwellings are less likely to make changes. Households living in colder climates also appear to change settings more often, presumably in response to more extreme temperatures. Households with more occupants over the age of 65 are also more likely to change the heating setting during the day.

Table 5 presents similar results for cooling settings. Households that pay for central AC are more likely to make changes to their cooling settings at any point in time during the day and also between evening and night. They are less likely to do so however if they live in large apartment buildings. Older residents are also more likely to make changes to their cooling settings. Most of the other demographic coefficients are not statistically significant.

[Table 5 about here]

The picture that emerges from the heating and cooling results is one where households are more likely to engage in some form of energy economizing behavior if they pay for their heating or cooling. The results are somewhat stronger for heating than central cooling. Interestingly, the extent to which households engage in this form of economizing behavior depends on the opportunities for improving comfort available. Households living in colder areas are more likely to keep their homes cooler but also more likely to keep their homes cooler at night than during in the evening and morning. This suggests that the response to economic incentives may in fact be larger when the opportunities for savings are more substantial.

5.1.3. *Robustness to unobserved heterogeneity.* We recognize that if there is unobserved heterogeneity across households that is somehow correlated with the decision of whether to pay for heating or cooling, we may have an endogeneity concern. While it is plausible to us that whether a housing contract includes the cost of heating or cooling is a secondary issue to more important factors that individuals consider when choosing where to live, we feel it is still worthwhile to perform an additional robustness check. Our cross-sectional dataset does not allow for household fixed or random effects in the previous regressions, but by focusing on *within-day* choices, we can construct a panel dataset. Then, we can consider the choice to change heating and cooling settings between morning and day, day and evening, evening and night and night and morning as choices made by the same household during four consecutive choice occasions. This allows us to include household-specific effects for these choices under the assumption that we observe choices for $T = 4$ choice occasions. Table 6 reports the estimated marginal effects from a random effects probit model.

[Table 6 about here]

The results presented in Table 6 suggest that our previous results are likely to be robust to unobserved household-level heterogeneity. Households who pay for heating have a large and statistically significant propensity to adjust heating settings during the day. However, they are less likely to adjust their heating settings if they live in apartment buildings. Households are more likely to adjust their settings when they live in colder areas. Wealthier (and more educated) individuals are more likely to optimize during the day. Similar but weaker results are obtained for cooling decisions.

5.2. **Insulation.** In Table 7 we investigate the extent to which the presence of either attic/ceiling insulation or exterior wall insulation in a home is related to whether the occupant owns the dwelling (box (2) in Figure 1). We perform the estimation for both attic/ceiling insulation (first three columns) and wall insulation (latter three columns), and we interact home ownership with paying for heating and central cooling.

[Table 7 about here]

Several of these results match our theoretical predictions well. Owner-occupied dwellings where the resident pays for heating (box (1) in Figure 1) are roughly 20 percent more likely to be insulated in the attic/ceiling. A joint test of the coefficients indicates that this result is statistically significant to the 1 percent confidence level. Similarly, owner-occupied dwellings where the resident pays for heating are roughly 13 percent more likely to be insulated in the exterior walls. This result is statistically significant to the 10 percent level with a joint test of the coefficients. Owner-occupied dwellings where the resident pays for central cooling are also roughly 20 percent more likely to be insulated in the attic/ceiling – again a statistically significant result. Moreover, rented dwellings where the resident pays for heating (box (2) of Figure 1) are 9 percent less likely to be insulated in the exterior walls, a result statistically significant at the 10 percent level. Combined, these results provide clear evidence for a split incentive issue in insulation that corresponds with the theoretical predictions discussed above.

Some of the other results in Table 7 do not have as clear of an interpretation. For example, owner-occupied dwellings where the resident does not pay for heating or cooling (box (3) in Figure 1) are 23 percent more likely to be insulated in the attic/ceiling. Owner-occupied dwellings where the resident does not pay for heating or cooling are 4 percent more likely to be insulated in the exterior walls, but this result is not statistically significant. Recall that there was not a strong theoretical prediction for box (3) in Figure 1, for the result depended on the nature of the housing where people own their dwelling but do not pay for their heating or cooling. Thus, we deem these results as indicative that in these cases the building manager who provides and pays for the heating or cooling was also involved in the construction of the building, and thus was more likely to ensure that the dwelling was insulated.

In all cases insulation is more likely to be present in colder areas and in homes with a programmable thermostat. Larger homes tend to be better insulated and homes in Southern California are more likely to lack insulation. This suggests that homeowners in colder areas are more likely to insulate their dwelling. We also find that attic/ceiling insulation is less likely in multi-unit complexes.

6. Energy Savings and Emissions Reductions

What energy savings and emissions reductions could we anticipate if we found a way to entirely correct these split incentive issues? We perform a series of back-of-the-envelope calculations to get a sense of the magnitude of the energy savings and emissions reductions that could be achievable from fully correcting each of the split incentive issues. The details of these calculations are described in Appendix A. Throughout the calculations, we strive to make generous assumptions, so that our estimates can be considered as a rough upper bound. We recognize that our back-of-the-envelope methodology abstracts from some details, but we intend for it to captures the most important factors of interest.

A primary finding is that the energy savings and emissions reductions from addressing the insulation split incentive issue would be quite a bit larger than the corresponding savings from addressing the heating or cooling split incentive issue. This result is driven both by the number of households that may be affected by the issue as well as the empirically estimated magnitude of the issue.

We find that renters who use natural gas for heating and cooling would save roughly 605 ft^3 of natural gas per year if the insulation split incentive issues was corrected for both wall and attic/ceiling insulation. Just over half of this savings is from heating. For comparison purposes, the sample average natural gas usage is 32,572 ft^3 per year. Renters who use electricity for heating and cooling would save roughly 21 kWh/year, with just over half of this savings from heating. The sample average electricity usage (for all purposes, not just heating or cooling) is 4,048 kWh/year. Since 75 percent of the households use natural gas for heating, and nearly 100 percent use electricity for cooling, the resulting energy savings for any given household will likely involve some natural gas savings and some electricity savings. Looking at the magnitude of the savings, it is clear that correcting the insulation split incentive problem may yield noticeable energy savings, yet these savings are relatively small compared to the energy usage of an average household.

The corresponding carbon dioxide emissions reductions come out to 9.15 kg C/year per household. Extrapolating to the roughly 12 million households in California, the reductions are on the order of 109,800 metric tons of CO_2 per year. Just over half of these emissions reductions are from wall insulation, and the rest are from attic or ceiling insulation improvements. Relative to the 2007 residential (non-electric) CO_2 emissions for California of 28 million metric tons of CO_2, these emissions reductions are extremely small. For a rough sense of the cost of improving the insulation, the cost for fiberglass insulation is in the range of \$0.30 per ft^2 for R-13 or \$0.90 per ft^2 for R-30 insulation.[12] So for a 1,000 ft^2 roof, the difference is \$900.

To calculate the energy savings possible from fully addressing the heating split incentive issue we adjust the probability that households keep their temperature at each of the settings by the empirically estimated marginal effects from the ordered probit regressions. We calculate that a 5

[12]These values are from the authors' observations at the local Home Depot.

degree decrease in heating temperature setting corresponds to an energy savings of roughly 2,500 ft^3 of natural gas per year or 75 kWh per year, depending on the heating fuel. Using these values and extrapolating to California, we find emissions reductions of roughly 10,500 metric tons CO_2 per year. Correcting for this issue with central cooling would yield a similar, but slightly smaller emissions reduction.

The relatively small magnitude of emissions reductions from correcting the heating or cooling split incentive issues is due both to the moderate behavioral changes in our empirical results and to the fact that in our sample only 5 percent of Californians do not pay for their own heat (using sample weights). While this small percentage may seem surprising, a comparison with the 2005 Residential Energy Consumption Survey (RECS) indicates that nationwide only about 5 percent do not pay for electric heat, 4 percent do not pay for central cooling, and 11 percent do not pay for natural gas heating. Thus, the RASS data on paying for heat in California appear quite reasonable, and we feel comfortable that our back-of-the-envelope calculation gives a helpful sense of what can be achieved.

7. Conclusions

This study lays out a conceptual framework to elucidate when and how split incentives could lead to principal-agent problems in two important cases: (1) when owners pay for heating or cooling and occupants face zero marginal cost for these energy services and (2) when occupants who pay for heating or cooling and cannot perfectly observe the prior choice of insulation by the owner. We test the theoretical implications in order to provide some of the first empirical evidence quantifying the effects of split incentives in both situations.

We find some evidence that paying for heating affects the heating or cooling temperature setting. We find stronger evidence that occupants who pay for heating *change* their heating setting more often than those who do not. For example, those who pay for heating are 16 percent more likely to turn down their heat at night. This suggests that those who are paying for heating are also thinking much more about their heating bill and putting in more effort to reduce their heating bill. The same split incentive issue also appears to hold for central air conditioning, although slightly less strongly.

There is also a clear mapping between our theoretical and empirical results on a split incentive issue relating to ownership of the dwelling and the degree to which the dwelling is insulated. For example, if the dwelling is owner-occupied and the resident pays for heating or cooling, the attic/ceiling is roughly 20 percent more likely to be insulated, and the exterior walls are roughly 13 percent more likely to be insulated. Both the insulation and heating/cooling results match the theoretical predictions of our conceptual framework.

Given the amount of policy discussion about principal-agent problems in energy use, we found it illustrative to calculate rough estimates of the energy savings and emissions reductions possible from completely correcting these split incentive issues. Our estimates indicate that the split incentive issue relating to insulation leads to greater additional energy consumption and emissions than the split incentive issue from not paying for energy use. Specifically, split incentive problems may increase total natural gas use by as much as 2 percent and total electricity use by as much as 1 percent. The emissions reductions from fully addressing the insulation split incentive issue in California are estimated to be roughly 109,800 metric tons of CO_2 per year, while the reductions from fully addressing the heating split incentive issue in California are estimated to be 10,500 metric tons of CO_2 per year. This difference is driven both by our empirical estimates and by the much larger number of households occupied by renters who pay for energy use (box (2) in Figure 1) than the number of households where the occupant does not pay for energy use (boxes (3) and (4) in Figure 1). Importantly, our estimates are quite small relative to total residential emissions, suggesting that if the policy goal is to reduce emissions substantially, split incentive issues should be a sidelight to a broader climate change policy.

Of course, even if the residential split incentive issues are not large relative to total emissions, there may be low-cost targeted policies that could improve economic efficiency by helping to address these issues. For instance, since the insulation issue inherently involves asymmetric information, information programs, such as required insulation quality disclosure on rental leases, may be a cost-effective approach. It may also be possible that providing consumers real-time feedback on electricity use and emissions may lead households motivated by environmental concerns to exert more effort to save energy. Minimum standards on new rental units may cost-effectively help to address the insulation split-incentive issue. Analyzing the effects of these policies on reducing the importance of split incentive issues in the owner-occupant relationship is a promising area of future research.

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REFERENCES

ALCHIAN, A., AND H. DEMSETZ (1972): "Production, Information Costs, and Economic Organization," *American Economic Review*, 62, 777–795.

ARROW, K. (1963): *Social Choice and Individual Values*. Wiley: New York.

BLUMSTEIN, C., B. KRIEG, L. SCHIPPER, AND C. YORK (1980): "Overcoming Social and Institutional Barriers to Energy Conservation," *Energy*, 5(4), 355–371.

BORENSTEIN, S. (2008): "Equity Effects of Increasing-Block Electricity Pricing," University of California Energy Institute CSEM WP 180.

——— (2009): "To What Electricity Price Do Consumers Respond? Residential Demand Elasticity Under Increasing-Block Pricing," UC Berkeley Working Paper.

CALIFORNIA ENERGY COMMISSION (2003): "California's Electricity Generation and Transmission Interconnection Needs Under Alternative Scenarios," Discussion paper, Prepared by Electric Power Group, LLC.

DAVIS, L. (2009): "Evaluating the Slow Adoption of Energy Efficient Investments: Are Renters Less Likely to Have Energy Efficient Appliances?," UC-Berkeley mimeo.

EIA (2008): "Annual Energy Outlook 2008," .

FISHER, A., AND M. ROTHKOPF (1989): "Market Failure and Energy Policy: A Rationale for Selective Conservation," *Energy Policy*, 17(4), 397–406.

GILLINGHAM, K., R. NEWELL, AND K. PALMER (2006): "Energy Efficiency Policies: A Retrospective Examination," *Annual Review of Environment and Resources*, 31, 193–237.

——— (2009): "Energy Efficiency Economics and Policy," *Annual Review of Resource Economics*, 1, 597–619.

GROSSMAN, S., AND O. HART (1982): *Economics of Information and Uncertainty* ,chap. Corporate Financial Structure and Managerial Incentives, (ed) J McCall. University of Chicago Press: Chicago, IL.

INTERNATIONAL ENERGY AGENCY (2007): "Mind The Gap: Quantifying Principal-Agent Problems in Energy Efficiency," Discussion paper, OECD/IEA.

ITO, K. (2010): "How Do Consumers Respond to Nonlinear Pricing? Evidence from Household Electricity Demand," *UC-Berkeley Working Paper*.

JAFFE, A., AND R. STAVINS (1994): "The Energy Efficiency Gap: What Does it Mean?," *Energy Policy*, 22(10), 804–810.

JENSEN, M., AND W. MECKLING (1976): "Theory of the Firm: Managerial Behavior, Agency Costs and Ownership Structure," *Journal of Financial Economics*, 3, 305–360.

LAFFONT, J.-J., AND D. MARTIMORT (2001): *The Theory of Incentives: The Principal-Agent Model*. Princeton University Press.

LEVINSON, A., AND S. NIEMANN (2004): "Energy Use by Apartment Tenants When Landlords Pay for Utilities," *Resource and Energy Economics*, 26(1), 51–75.

MURTISHAW, S., AND J. SATHAYE (2006): "Quantifying the Effect of the Principal-Agent Problem on US Energy Use," Discussion paper, Lawrence Berkeley National Laboratory, LBNL-59773.

NADEL, S. (2002): "Appliance and Equipment Efficiency Standards," *Annual Review of Energy and the Environment*, 27, 159–192.

NEW YORK TIMES (2010): "Air-Conditioners That Run When Nobodys Home," *August 15*.

SPENCE, M., AND R. ZECKHAUSER (1971): "Insurance, Information, and Individual Action," *American Economic Review*, 61(2), 380–387.

US CENSUS BUREAU (2010): "Current Population Survey/Housing Vacancy Survey," .

APPENDIX A. ENERGY SAVINGS AND EMISSIONS REDUCTIONS CALCULATIONS

This appendix describes the assumptions used in the back-of-the-envelope calculations of the energy savings and emissions reductions. All calculations use the sample weights included the RASS dataset. First, we describe the calculations for an estimate of the energy savings from addressing the insulation split incentive issue, then move on to energy savings from the heating split incentive issue, and finally describe the conversion factors used to calculate emissions reductions.

The methodology for calculating energy savings from correcting the insulation split incentive issue is based on the following physical relationship:

$$HL = TD \cdot A/R,$$

where HL is the rate of heat loss, TD is the differential between the inside and outside temperature, A is the surface area by which heat can escape, and R is the R-value of the insulation (a measure of insulation quality). To calculate the temperature differential, we first find daily data on the high, low, and average temperature at test stations in each county in California from the UC IPM Online: Statewide Integrated Pest Management Program (www.ipm.ucdavis.edu). We use the average high-low-average temperature for each county in California and match these by county to the observations in our dataset. For the three counties that did not have a test station, we choose an adjacent county that to the best of our knowledge has a similar climate. We then calculate the temperature difference between the observed indoor temperature in each time of day, and the high temperature for daytime, the low temperature for nighttime, and the average temperature for morning and evening. This gives us a temperature difference for each day of the year and for each of the four times-of-day.

To calculate the surface area in square feet, we make the following assumptions: single-family homes are square and have all four walls exposed to the outside, townhouses are rectangles and have two walls exposed to the outside, 2-4 unit apartments are square and have two walls exposed to the outside, and 5+ unit apartments are square and have one wall exposed to the outside. We then use the observed square footage of the dwelling, observed number of stories of the dwelling, and an assumed height of 12 feet per story to calculate the wall area and ceiling area. For single-family homes and townhouses, we assume that the roof has a pitch such that the surface area is 1.2 times a flat roof.

We take R-values of the insulated apartments from the Department of Energy suggested insulation levels for California. These are R-values of 5 for walls and 30 for attics/ceilings. For poorly insulated dwellings, we use an estimate of 3 for walls and 9 for attics/ceilings. We can then calculate the rate of heat loss by time of day and day of year. These estimates are then aggregated for both heating and cooling and converted to cubic feet of natural gas or kWh of electricity. Then we use our marginal effects from Table 7 to calculate how many more observations in our sample would be insulated if the split incentive issue did not exist. In other words, for renters we increased the sample probability of being insulated by 20 percent for attic/ceiling insulation and 13 percent for wall insulation. We then can calculate the total energy savings (in natural gas or electricity) between the current case and the counterfactual where the insulation split incentive issue was entirely corrected.

To find the energy savings from addressing the heating split incentive issue, we begin by performing a simple linear fit of the heating setting at each time of day on the household yearly natural gas use and all of the covariates used in Table 5 for households that use natural gas. For households that use electricity, we perform a similar linear fit on the household yearly electricity consumption. For all four time periods, the result for natural gas indicates that a one degree increase in heating setting corresponds to roughly 2,500 ft^3 per year in additional natural gas use. For electricity, the estimation result indicates that a one degree increase in heating setting corresponds to roughly 75 kWh per year in additional electricity use.

We then use a similar methodology as for insulation, by focusing on those who do not pay for heat and changing the sample probability of being in one of the heating setting categories by the marginal effects estimated in the ordered probit estimation. The calculation is done separately for those who use natural gas and electricity. These give a result of the number in the sample who currently are in some (e.g., high) heating setting but in the counterfactual when the split incentive issue is corrected, would be in a different (e.g., lower) heating setting. This number is multiplied by the energy savings to get the total energy savings. Note that when our sample is extrapolated out to the population of California, the data indicate that 95 percent of residents pay for heat at their dwelling. So the resulting energy savings and carbon dioxide emissions reflect this relatively small number who do not pay for heating. On the other hand, roughly 25 percent of the dwellings are rented.

Carbon dioxide emissions reductions are based on carbon intensity of natural gas (1 m^3 = 0.49 kg carbon) for those who use natural gas, and the average carbon intensity of electricity in California (1 MJ = 0.01 kg carbon) based on estimates of the primary energy sources used California in 2003 (California Energy Commission 2003). To the extent that California's electric power sector is further de-carbonizing, this estimate is an over-estimate.

	Occupant owns	Occupant rents
Occupant pays for energy use	(1) No split incentives	(2) (owner) Under-insulation & less efficient appliances; optimal effort to reduce energy use
Occupant does not pay for energy use	(3) (both) Lower effort to reduce energy use; [under-insulation & less efficient appliances]	(4) (occupant) Lower effort to reduce energy use; ambiguous effect on insulation & appliances

FIGURE 1. Matrix of possible avenues for split incentives in the owner-occupant relationship. The agent making the hidden action in the owner-occupant problem is indicated in parentheses.

TABLE 1. Summary Statistics

Variable	Mean	Std Dev	Min	Max	N
Heating/Cooling Setting, Higher ⇒ Warmer					
Heating setting in morning	3.67	0.99	1	6	13,641
Heating setting in day	3.34	1.10	1	6	10,857
Heating setting in evening	3.81	0.90	1	6	14,120
Heating setting at night	3.04	1.16	1	6	11,085
Central cooling setting in morning	4.42	1.75	1	6	8,732
Central cooling setting in day	3.81	1.69	1	6	8,732
Central cooling setting in evening	3.51	1.62	1	6	8,732
Central cooling setting at night	4.48	1.74	1	6	8,732
Dwelling Type					
Live in single family homes	0.66	0.47	0	1	20,933
Live in townhouses	0.09	0.29	0	1	20,933
Live in 2-4 unit apartments	0.08	0.27	0	1	20,933
Live in 5+ unit apartments	0.16	0.37	0	1	20,933
Dwelling Characteristics					
Own dwelling (not renting)	0.73	0.45	0	1	20,604
Exterior walls insulated	0.73	0.44	0	1	18,418
Attic and ceiling insulated	0.76	0.43	0	1	18,062
House square footage (1,000 ft^2)	1.56	0.81	0.2	6	20,905
Age of dwelling (years)	33.67	18.02	0	68	20,933
Own a spa	0.11	0.32	0	1	20,933
Own a pool	0.09	0.29	0	1	20,933
Live in home year-round	0.98	0.14	0	1	20,933
Heating degree days (65 degree)	2.09	0.81	0.98	5.3	20,933
Cooling degree days (65 degree)	0.88	0.77	0	4.3	20,933
Heating System Characteristics					
Pay for heating	0.95	0.21	0	1	20,772
Pay for central cooling	0.45	0.50	0	1	20,736
Primary heating is electricity	0.12	0.32	0	1	19,960
Electric price	14.92	4.00	7.3	25.8	20,933
Primary heating is natural gas	0.81	0.39	0	1	19,968
Primary heating is bottled gas	0.04	0.20	0	1	19,968
Heating programmable thermostat	0.35	0.48	0	1	20,933
Heating system age (years)	16.58	12.49	1	40	18,093
Central cool programmable thermostat	0.24	0.43	0	1	20,933
Central cool system age (years)	11.54	9.04	1	40	9,129
Resident Characteristics					
Household income (dollars)	64,878	45,995	4,272	431,189	20,904
Number living in household	2.67	1.55	1	10	20,345
Number of children	0.69	1.14	0	8	20,344
Number of seniors	0.46	0.76	0	8	20,345
Utility					
Annual electricity consumption	5,948	4,194	0	71,268	20,518
PG&E	0.44	0.50	0	1	20,933
SDG&E	0.12	0.33	0	1	20,933
SCE	0.37	0.48	0	1	20,933
LADWP	0.07	0.25	0	1	20,933

TABLE 2. Cross-tabulations Corresponding to Figure 1

	Own dwelling	Rent dwelling	Total
Pay for heating	7,742	2,242	9,984
Do not pay for heating	50	209	259
Total	7,792	2,451	10,243

	Own dwelling	Rent dwelling	Total
Pay for central cooling	4,902	1,162	6,064
Do not pay for central cooling	1,506	1,092	2,598
Total	6,408	2,254	8,662

Note: the top matrix is restricted to the heating subsample; the bottom matrix is restricted to the cooling subsample.

TABLE 3. Morning Heating Ordered Probit Marginal Effects

	(1) below 55	(2) 55-60	(3) 61-65	(4) 66-70	(5) 71-75	(6) over 75
Pay for heating	0.027**	0.077	0.159	-0.009	-0.175	-0.079
	(0.012)	(0.056)	(0.195)	(0.219)	(0.269)	(0.212)
Pay & ext walls insulated	0.010	0.022	0.030	-0.028	-0.027	-0.007
	(0.028)	(0.064)	(0.091)	(0.076)	(0.084)	(0.022)
Pay & attic/ceiling insulated	-0.294	-0.223***	-0.054	0.405*	0.140***	0.026**
	(0.388)	(0.059)	(0.146)	(0.237)	(0.052)	(0.013)
Own dwelling	0.005	0.010	0.013	-0.014	-0.012	-0.003
	(0.003)	(0.007)	(0.009)	(0.008)	(0.008)	(0.002)
Square ft of living space	0.003**	0.007**	0.009**	-0.009**	-0.008**	-0.002**
	(0.001)	(0.003)	(0.004)	(0.004)	(0.003)	(0.001)
Exterior walls insulated	-0.008	-0.017	-0.020	0.023	0.018	0.004
	(0.037)	(0.072)	(0.082)	(0.104)	(0.072)	(0.015)
Attic/ceiling insulated	0.051**	0.131***	0.264**	0.074	-0.302**	-0.219
	(0.022)	(0.046)	(0.108)	(0.271)	(0.118)	(0.328)
Live in home year-round	-0.008	-0.015	-0.017	0.021	0.015	0.003
	(0.010)	(0.019)	(0.021)	(0.028)	(0.018)	(0.004)
Age of home (decades)	0.002***	0.003***	0.004***	-0.005***	-0.004***	-0.001***
	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.000)
Primary heating is electricity	0.022	0.040	0.042	-0.059	-0.037	-0.008
	(0.022)	(0.036)	(0.030)	(0.056)	(0.027)	(0.005)
Primary heating is nat gas	-0.007*	-0.014**	-0.017**	0.020*	0.015**	0.003**
	(0.004)	(0.007)	(0.008)	(0.010)	(0.007)	(0.002)
Heating degree days	0.005**	0.011**	0.014**	-0.015**	-0.012**	-0.003**
	(0.002)	(0.004)	(0.006)	(0.006)	(0.005)	(0.001)
Programmable thermostat	-0.009***	-0.018***	-0.022***	0.024***	0.020***	0.005***
	(0.002)	(0.004)	(0.005)	(0.006)	(0.005)	(0.001)
Electric heat*electric price	-0.001	-0.002	-0.003	0.003	0.003	0.001
	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)
log(income)	-0.002	-0.004	-0.005	0.005	0.004	0.001
	(0.002)	(0.004)	(0.004)	(0.005)	(0.004)	(0.001)
Number of occupants	-0.000	-0.001	-0.001	0.001	0.001	0.000
	(0.001)	(0.002)	(0.003)	(0.003)	(0.003)	(0.001)
Number of children	-0.003*	-0.006*	-0.007*	0.008*	0.006*	0.001*
	(0.002)	(0.003)	(0.004)	(0.005)	(0.004)	(0.001)
Number of 65+ occupants	-0.010***	-0.020***	-0.026***	0.028***	0.023***	0.005***
	(0.001)	(0.003)	(0.004)	(0.004)	(0.003)	(0.001)
Utility Controls	Y	Y	Y	Y	Y	Y
Education Controls	Y	Y	Y	Y	Y	Y
Climate Zone Controls	Y	Y	Y	Y	Y	Y
Observations	6,060	6,060	6,060	6,060	6,060	6,060
Pr(setting)	3.2	9.9	25.9	48.8	10.4	1.68

*** indicates significant at 1 percent level, ** at 5 percent level, * at 10 percent level
Heteroskedasticity-robust standard errors in parentheses

TABLE 4. Marginal Effects for Probit Estimations of Changes of Heating Setting

	(1) anytime	(2) mrn to evn	(3) evn to night	(4) evn > night	(5) night to mrn	(6) night < morn
Pay for heating	0.11**	0.06	0.16**	0.09	0.15**	0.10
	(0.05)	(0.06)	(0.07)	(0.07)	(0.07)	(0.07)
Townhouse	-0.01	0.02	-0.01	0.00	-0.01	-0.03
	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
2-4 unit Apt	-0.08***	-0.05**	-0.05**	-0.05**	-0.10***	-0.09***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
5+ unit Apt	-0.08***	-0.03	-0.06***	-0.05***	-0.08***	-0.10***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Own dwelling	0.01	0.01	0.04**	0.07***	0.03**	0.07***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)
Square ft of living space	-0.02***	-0.01*	-0.00	0.00	-0.00	0.01
	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Exterior walls insulated	-0.03***	-0.02*	-0.03***	-0.05***	-0.02*	-0.03**
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Attic/ceiling insulated	0.00	-0.01	0.04***	0.07***	0.03***	0.06***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Live in home year-round	-0.01	-0.03	0.03	0.01	-0.01	-0.01
	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Age of home (decades)	0.02***	0.00*	0.02***	0.02***	0.01***	0.02***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Primary heating is electricity	0.04	0.09	0.01	-0.00	0.02	-0.02
	(0.04)	(0.06)	(0.06)	(0.06)	(0.06)	(0.07)
Primary heating is nat gas	-0.01	0.04**	0.03	0.02	0.04**	0.02
	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Heating degree days	0.04***	0.01	0.05***	0.06***	0.04***	0.05***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Programmable thermostat	0.03***	-0.04***	0.09***	0.11***	0.09***	0.12***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Electric heat*electric price	-0.00*	-0.00	-0.00	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
log(income)	-0.00	-0.01	0.02**	0.03***	0.00	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Number of occupants	-0.01*	0.00	-0.02***	-0.04***	-0.01***	-0.03***
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)
Number of children	-0.00	-0.01	-0.00	-0.01	0.01	0.00
	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Number of 65+ occupants	0.02***	-0.01*	0.04***	0.06***	0.06***	0.09***
	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
SDG&E	-0.03	-0.01	-0.01	-0.02	0.01	0.03
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Southern California Edison	-0.01	0.01	-0.00	-0.02	-0.00	-0.00
	(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
LA Dept Water & Power	-0.02	-0.00	-0.04	-0.06	-0.00	-0.03
	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Education Controls	Y	Y	Y	Y	Y	Y
Climate Zone Controls	Y	Y	Y	Y	Y	Y
Observations	13,392	13,392	13,392	13,392	13,392	13,392
Dependent Var Mean	0.81	0.39	0.64	0.57	0.58	0.49

*** indicates significant at 1 percent level, ** at 5 percent level, * at 10 percent level
Heteroskedasticity-robust standard errors in parentheses

TABLE 5. Marginal Effects for Probit Estimations of Changes of Central Cooling Setting

	(1) anytime	**(2)** mrn to evn	**(3)** evn to night	**(4)** evn < night	**(5)** night to mrn	**(6)** night > morn
Pay for central AC	0.09**	0.06	0.13***	0.12***	0.01	-0.03
	(0.02)	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)
Townhouse	-0.01	0.01	0.01	-0.01	0.00	-0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
2-4 unit Apt	-0.01	0.01	-0.01	-0.04	0.02	-0.01
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)
5+ unit Apt	-0.06**	-0.06**	-0.05*	-0.06**	0.00	0.00
	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)
Own dwelling	0.02	0.00	0.03	0.03	-0.01	0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Square ft of living space	-0.03***	-0.01	-0.02	-0.01	-0.02**	-0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Exterior walls insulated	-0.06***	-0.03*	-0.04**	-0.05**	-0.02	-0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)
Attic/ceiling insulated	0.04**	0.04*	0.03	0.02	-0.01	-0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Live in home year-round	0.07	0.12**	0.14***	0.11**	0.06	0.00
	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.04)
Age of home (decades)	0.01***	0.01***	0.01***	0.01***	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Programmable thermostat	-0.06***	-0.04***	-0.01	-0.01	0.02	0.02*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Cooling-degree-days/100	-0.00	-0.01	-0.00	-0.00	0.00	0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Cooling system age	-0.00***	-0.00	-0.00	0.00	-0.00***	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
log(income)	0.01	0.03**	0.02*	0.02*	0.00	-0.02**
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Number of occupants	-0.01	-0.00	-0.01	-0.00	-0.02***	-0.02***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Number of children	-0.00	-0.01	-0.02**	-0.02***	0.02**	0.02**
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Number of 65+ occupants	0.02***	-0.01	0.05***	0.04***	0.03***	0.04***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
SDG&E	-0.04	-0.06	0.01	-0.00	0.05	0.03
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)
Southern California Edison	-0.02	-0.03	-0.01	-0.03	0.08***	0.03
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)
LA Dept Water & Power	-0.06	-0.08	-0.05	-0.04	0.06	0.05
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)
Electric price (c/kWh)	-0.00**	-0.00	-0.00*	-0.00**	0.00	0.00*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Education Controls	Y	Y	Y	Y	Y	Y
Climate Zone Controls	Y	Y	Y	Y	Y	Y
Observations	6,846	6,846	6,846	6,846	6,846	6,846
Dependent Var Mean	0.69	0.45	0.47	0.40	0.27	0.14

*** indicates significant at 1 percent level, ** at 5 percent level, * at 10 percent level
Heteroskedasticity-robust standard errors in parentheses

TABLE 6. Marginal Effects for Random Effects Probit Estimation of Changes of Heating/Cooling Setting

	(1) heating	**(2)** cooling
Pay for heating	0.51***	
	(0.18)	
Pay for central AC		0.11
		(0.08)
Townhouse	-0.01	0.01
	(0.04)	(0.04)
2-4 unit Apt	-0.26***	0.03
	(0.05)	(0.06)
5+ unit Apt	-0.24***	-0.08
	(0.05)	(0.05)
Own dwelling	0.14***	0.12***
	(0.04)	(0.04)
Square ft of living space	-0.06***	-0.08***
	(0.02)	(0.02)
Exterior walls insulated	-0.09***	-0.11***
	(0.03)	(0.04)
Attic/ceiling insulated	0.09***	0.12***
	(0.03)	(0.04)
Live in home year-round	0.09	0.24**
	(0.09)	(0.10)
Age of home (decades)	0.05***	0.02**
	(0.01)	(0.01)
Programmable thermostat	0.30***	0.01
	(0.02)	(0.02)
log(income)	0.07***	0.02
	(0.02)	(0.02)
Primary heating is electricity	0.16	
	(0.16)	
Primary heating is nat gas	0.12**	
	(0.05)	
Electric heat*electric price	-0.02*	
	(0.01)	
Heating degree days	0.13***	
	(0.03)	
Cooling-degree-days/100		-0.03
		(0.02)
Electric price (c/kWh)		-0.00
		(0.00)
Education Controls	Y	Y
Climate Zone Controls	Y	Y
Household Random Effects	Y	Y
Observations	55,544	28,344

*** indicates significant at 1 percent level, ** at 5 percent level, * at 10 percent level
Heteroskedasticity-robust standard errors in parentheses

TABLE 7. Marginal Effects for Probit Insulation Estimations

	(1) Attic/Ceil	(2) Attic/Ceil	(3) Attic/Ceil	(4) Wall	(5) Wall	(6) Wall
Own dwelling	0.17***	0.20*	0.23**	0.12***	0.07	0.04
	(0.05)	(0.11)	(0.12)	(0.05)	(0.11)	(0.10)
Pay for heating	0.03	0.05	0.07	-0.03*	-0.10**	-0.09*
	(0.02)	(0.07)	(0.07)	(0.02)	(0.05)	(0.05)
Own*Pay for heating	0.04	0.01	-0.03	0.02	0.06	0.09
	(0.04)	(0.08)	(0.08)	(0.04)	(0.10)	(0.11)
Pay for central AC	0.10***	0.06***	0.05***	0.10***	0.07***	0.07***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)
Own*Pay for cent AC	-0.00	-0.00	-0.01	-0.03*	-0.03	-0.03
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)
Townhouse	-0.12***	-0.10***	-0.10***	-0.02*	0.00	0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
2-4 unit Apt	-0.21***	-0.17***	-0.17***	-0.03*	-0.01	-0.01
	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)
5+ unit Apt	-0.23***	-0.18***	-0.20***	-0.00	0.01	0.01
	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)
Square ft of living space	0.03***	0.03***	0.02***	0.06***	0.07***	0.07***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Live in home year-round	0.08***	0.09***	0.08***	-0.06***	-0.02	-0.01
	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)
Age of home (decades)	-0.04***	-0.04***	-0.04***	-0.08***	-0.07***	-0.07***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
SDG&E	-0.04***	0.02	0.01	-0.04***	-0.01	-0.03
	(0.01)	(0.02)	(0.03)	(0.01)	(0.03)	(0.03)
Southern California Edison	-0.04***	-0.02	-0.02	-0.03***	-0.01	-0.03
	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)
LA Dept Water & Power	-0.14***	-0.11***	-0.11***	-0.06***	-0.02	-0.03
	(0.02)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)
Primary heating is electricity		-0.00	-0.01		0.02	0.01
		(0.04)	(0.04)		(0.04)	(0.04)
Heating degree days		0.02**	0.02**		0.05***	0.05***
		(0.01)	(0.01)		(0.01)	(0.01)
Cooling-degree-days/100		0.01	0.01		0.02*	0.02**
		(0.01)	(0.01)		(0.01)	(0.01)
Programmable thermostat		0.06***	0.06***		0.03***	0.02***
		(0.01)	(0.01)		(0.01)	(0.01)
Electric heat*electric price		-0.00	-0.00		0.00	0.00
		(0.00)	(0.00)		(0.00)	(0.00)
log(income)			0.02***			0.01**
			(0.00)			(0.01)
Number of occupants			-0.01**			0.01
			(0.00)			(0.00)
Number of children			-0.00			-0.01
			(0.00)			(0.01)
Number of 65+ occupants			0.02***			-0.01***
			(0.00)			(0.00)
Education Controls	N	N	Y	N	N	Y
Climate Zone Controls	N	Y	Y	N	Y	Y
Observations	17,456	16,936	16,127	17,810	17,225	16,405

*** indicates significant at 1 percent level, ** at 5 percent level, * at 10 percent level
Heteroskedasticity-robust standard errors in parentheses