Appendix A. Contract Theory Model

In this section, removed from the manuscript at the request of the reviewers, we develop a stylized model to formalize why split incentives in the owner-occupant relationship may lead to an overconsumption of energy. This model provides the theoretical framework motivating our empirical analysis.

A.1. **Stylized model.** We formalize the conceptual framework developed above in a stylized model to more precisely develop testable implications for our empirical estimation. Consider a two player game where the players are the owner (who in some cases is a landlord) and occupant (who in some cases is a tenant). We begin by focusing on the situation where the occupant is a renter (the second column in Figure 1) and then analyze the case where the occupant is also the owner (the first column in Figure 1).

A.1.1. *Occupant is renting.* The game has four stages:

(1) The owner ("landlord") chooses $i \in \{I, NI\}$, where I denotes "invest" and NI denotes "not invest" in improving the energy efficiency of the dwelling (e.g., installing insulation or energy-efficient appliances). The cost of investing is given by $c_I > 0$ and there is no cost if no investment is made.
(2) Owner offers a contract $j \in \{P, NP\}$ to the occupant that either includes the cost of energy use in the contract (NP), or it does not (P). If the occupant does not accept the contract, the outside option is another dwelling that includes the cost of energy in the rent for a price of p_0.
(3) Contingent on the occupant accepting the contract, her or she chooses how much effort to exert to reduce energy use $e \in \{L, H\}$, where L refers to low effort and H refers to high effort. The cost of high effort is given by $c_E > 0$ and there is no cost for low effort.
(4) The payoffs are realized, which are based on the total cost of energy use $c_{EU}(i, e)$, where $c_{EU}(i, L) > c_{EU}(i, H)\ \forall\ i$ and $c_{EU}(NI, e) > c_{EU}(I, e)\ \forall\ e$.

To tie this game into our conceptual framework, we can note that in Figure 1, P corresponds to the contract offered in the first row and NP corresponds to the contract offered in the second row. Note that the basic setup of the game applies to both the first and second columns in Figure 1. Now we must make two additional reasonable assumptions for this game to provide useful predictions.

Assumption 1. $c_{EU}(NI, e) - c_{EU}(I, e) > c_I\ \forall\ e \in \{L, H\}$.

This assumption assures that regardless of the effort that the occupant will make to reduce energy use in stage 3, the energy bill savings from improving the energy efficiency of the building (e.g., insulating the building) are greater than the cost of insulating. When moving from very low insulation to the recommended insulation, this assumption should hold in most cases, except perhaps in cases with extremely moderate climates or when the home is a second home.

Assumption 2. $c_{EU}(i, L) - c_{EU}(i, H) > c_E \; \forall \, i \in \{I, NI\}$.

This second assumption assures that regardless of whether the owner has invested in energy efficiency or insulation, the energy bill savings from exerting effort to reduce the energy bill are always greater than the cost of exerting effort. We believe that this is quite reasonable in the range of empirically observed energy use. We can now examine the choice of investment.

Proposition 1. *If the landlord offers contract P to the occupant, then the landlord will not invest, i.e., $i = NI$. If the landlord offers contract NP to the occupant, then the landlord will invest, i.e., $i = I$.*

Proof. If the landlord offers contract P to the occupant, then by Assumption 2 the occupant knows he or she will optimally choose to exert high effort at a cost c_E and pay total energy use costs $c_{EU}(i, H)$ depending on the choice of i, where i here is the investment that the occupant believes was done. The landlord cannot credibly commit to making the investment, for not making the investment and claiming they had would be a profitable deviation in the first stage. Thus, the occupant believes that no investment was made when contract P is offered. Correspondingly, the landlord does not make the investment. If the landlord offers contract NP to the occupant, then our result follows directly from Assumption 1, for the reduced energy bill from investing is greater than the cost to the landlord of the investment. □

This first proposition applies directly to the upper-right element in Figure 1 (box (2)), where the occupant is renting and pays for energy use. The implication here is that we would expect to find under-investment in energy efficiency by the landlord. The second proposition addresses the choice of effort to reduce energy use.

Proposition 2. *If $c_{EU}(I, L) - c_{EU}(NI, H) > c_E - c_I$, then contract P is offered to the occupant and the occupant chooses effort H to reduce energy use. Otherwise, contract NP is offered and the occupant chooses effort L. When contract P is offered, the landlord's payoff is $p_0 - c_{EU}(NI, H) - c_E$. When contract NP is chosen, the landlord's payoff is $p_0 - c_{EU}(I, L) - c_I$.*

Proof. Suppose the landlord offers the tenant contract P. The highest price the occupant will be willing to pay is p_0 minus all costs relating to energy use (including conservation effort, if exerted), for the occupant pays for energy use under contract P and would not pay if they took the outside option. By Proposition 1, under contract P the landlord will not invest in energy efficiency improvements in the first stage. By Assumption 2, the occupant will choose to exert effort H to reduce energy use, thus bearing the cost c_E. Thus, the occupant bears the costs $c_{EU}(NI, H) + c_E$. The landlord can charge $p_0 - c_{EU}(NI, H) - c_E$ for rent, earning the landlord a payoff of $p_0 - c_{EU}(NI, H) - c_E$. If landlord offers the occupant contract NP, the highest price the tenant will be willing to pay is p_0 minus all costs related to energy use. Since the occupant does not pay for energy use under contract NP, he or she will choose not to exert effort to reduce their energy use (effort L). By Proposition 1, the landlord will invest in energy efficiency improvements in the first stage. The landlord can charge p_0 for rent, and thus will receive payoffs $p_0 - c_{EU}(I, L) - c_I$. Thus, the landlord will choose to offer contract P if $p_0 - c_{EU}(NI, H) - c_E > p_0 - c_{EU}(I, L) - c_I$, or $c_{EU}(I, L) - c_{EU}(NI, H) > c_E - c_I$. □

Proposition 2 shows that if the cost of investment is high or the cost of effort is low, then the landlord would offer a contract where the occupant pays, and otherwise will offer a contract where the occupant does not pay. Similarly, if the difference in energy use between the energy bill under the NP and P contracts is high, then the landlord will offer a contract where the occupant pays. Effectively, this result formalizes how the optimal contract chosen depends on the balance of the inefficiencies due to hidden action by the landlord (i.e., investment in energy efficiency) and hidden action by the occupant (i.e., effort to reduce energy use).

Proposition 2 has implications most directly relevant to the bottom-right element in Figure 1 (box (4)), where the occupant is a renter who does not pay for energy use, corresponding with contract NP. In this case, Proposition 2 predicts that the occupant will put in low effort (L) towards reducing energy use.

A.1.2. *Occupant is the owner.* When the occupant is the owner (the first column in Figure 1), the game is largely analogous, with only slight differences. Focusing on the bottom left element in Figure 1 (box (3)), we have a situation where the occupant owns the dwelling but does not pay for the energy use. The exact circumstances that cause this situation to come about will determine the stages of this game. We posit that this situation would only occur if considerable economies of scale exist in the provision of heating or cooling, and would be less likely to occur for a broader set of energy uses. When this situation occurs the entity who provides the heating or cooling will be a third party, which could be a community association or housing complex manager. One could imagine that in some cases the community association or housing complex manager is able to instate guidelines requiring a certain amount of insulation. But in others, the guidelines are lax and the occupant's decision of how much to insulate dominates on the margin. The following model elucidates this latter environment.

Our formal model begins with the premise that there is a housing complex with considerable economies of scale to providing heat or cooling and it is difficult to monitor the use of heating or cooling. Without loss of generality, we can focus on heating, which we denote with subscript "h". As before, assume there is an outside housing option that will provide heating or cooling for a price p_h^O. Consider the following three stages:

(1) The third party (e.g., community association) chooses the amount to charge for heating.
(2) Contingent on not moving, the owner-occupant chooses how much effort to exert to reduce energy use $e \in \{L, H\}$, where L refers to low effort and H refers to high effort. The cost of high effort is given by $c_E > 0$ and there is no cost for low effort. At the same time, the owner-occupant chooses $i \in \{I, NI\}$, where I denotes "invest" and NI denotes "not invest" in insulating the dwelling. The cost of insulating is given by $c_I > 0$ and there is no cost if no investment is made.
(3) The payoffs are realized, which are based on the total cost of heating $c_h(i, e)$, where $c_h(i, L) > c_h(i, H)\ \forall\, i$ and $c_h(NI, e) > c_h(I, e)\ \forall\, e$.

This setup has the following straightforward implication.

Proposition 3. *If $p_h^O > c_h(NI, L)$, then a contract exists where the third party charges a fixed community fee for heating of p_h^O, the owner-occupant exerts low effort to reduce energy use ($e = L$) and chooses not to insulate (i.e., $i = NI$). The payoff to the third party is $p_h^O - c_h(NI, L)$.*

Proof. In order to prevent the owner-occupant from moving, the third party can charge no more than p_h^O. Since there is a cost to insulating and putting in effort to reduce energy use, the owner-occupant will have no incentive to do so. The third party recognizes this, and thus will offer a contract to provide heating for p_h^O only if this payoff is greater than the cost of providing the heating $c_h(NI, L)$. □

This simple result provides two testable implications for behavior in the situation in bottom left element in Figure 1 (box (3)). One is the implication that the occupant will exert low effort to reduce energy use – just as in box (4) of Figure 1, for the incentives are the same in both cases. The second is the implication of under-insulation, which depends crucially on the assumption that there are no guidelines on minimum insulation in the housing complex. As mentioned above, this is an assumption that may or may not hold, but it worth examining empirically in more detail.

A.2. **Testable implications of the Model.** 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).
- 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 of 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).

The published version of the paper empirically tests these implications to quantify the extent of split incentives in residential energy use in California.

	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.