Quantifying the Effect of the Principal-Agent Problem on U.S. Residential Energy Use

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ABSTRACT

Quantifying the amount of energy associated with market failures helps to demonstrate the significance of energy efficiency policies beyond price signals. In this report we investigate the magnitude of the principal-agent (PA) problem affecting refrigeration, water heating, space heating, and lighting in the U.S. residential sector. We develop an approach for classifying households into a PA matrix for each end use that allocates end-use equipment into four different PA classifications based on household characteristics. End use energy values differentiated by housing unit type were used to estimate the total energy use associated with the PA problem. We find that the 2003 associated site energy use from these four end uses affected by the PA problem totaled over 3,400 trillion Btu, equal to 35% of the site energy consumed by the US residential sector. In addition, we also estimated an upper bound on annual hypothetical energy savings of 4.8 trillion Btu of site energy if there had been no PA problems affecting refrigerators and water heaters sold in 2003. This savings potential is considerably lower than it would have been in the absence of minimum energy performance standards. Policies and programs that would be effective differ among the four different classes of the PA problem.

Introduction

Many barriers to energy efficiency have been identified in the energy policy literature since the question of barriers to financially attractive investments in energy efficiency first began to attract attention in the 1970s and 1980s. Previous studies have focused largely on explaining why under-investments in energy efficiency are widespread, identifying the specific barriers responsible, and attempting to quantify the technical, economic (perfect markets), and market (actual conditions) scenarios for potential energy savings. Jaffe and Stavins (1994) and Sathaye et al. (2001) provide a classification of the many barriers and the corresponding energy saving potentials. They classify the types of barriers that could constitute market failures, which include the principal-agent (PA) and lack of information problems. Further, Sathaye and Murtishaw (2004) demonstrate the effects of lack of information and other barriers in explaining the difference between actual and estimated market penetration of energy efficient lighting in California that is apparently cost-effective.

Multiple barriers have been defined in these previous studies, but few studies to our knowledge have attempted to quantify the "excess" energy consumed due to any particular barrier or the savings potential from mitigating it. Based on the above experience, this study focused on the PA problem because quantifying its extent and the excess energy consumption it causes was thought to be more tractable than for other market failures.

The PA problem arises in many spheres of economic activity, when one person, the principal, hires an agent to perform tasks on his behalf but cannot ensure that the agent performs them in exactly the way the principal would like. The efforts of the agent are impossible or expensive to monitor and the incentives of the agent differ from those of the principal. Thus, the PA problem is a function of incentives, information asymmetry, and enforcement capacity.

In residential energy use, this commonly occurs in two critical transactions, one between home builders and prospective buyers, and the second between renters and landlords (Jaffe and Stavins 1994). Home builders may have difficulty conveying the benefits of cost-effective energy efficiency technologies to prospective buyers because these technologies and their future energy use consequences are not observable.[1] Likewise, landlords may not be able to recover all of the value of such investments in the form of higher rents in cases where renters pay fuel bills, and tenants may not be able to get reduced rents when they make these investments in cases where the landlord pays the energy bill.[2]

A PA problem can block or delay utility price signals from reaching the end-user, or prevent the end-user from acting on price signals. The findings of this study provide a quantitative basis for supporting government interventions that complement energy price signals for increasing the penetration of cost-effective energy efficient products.

The purpose of this study was to quantify both the number of US households affected by the PA problem and the associated site and primary energy use for refrigerators, water heaters, space heating and lighting. The "associated" energy refers to the total energy consumption of the end uses that are affected by PA problems; thus, the estimates of associated energy do not indicate how much more energy is consumed by these end uses than would otherwise occur. We also estimate the energy saving potential from overcoming the PA problem for refrigerators and water heaters. Note that due to space limitations, the underlying calculations are only shown for water heaters. More information on the other three end uses is available in Murtishaw and Sathaye (2006).[3]

The PA problem may be addressed through a market response such as the changes in rents noted above, or through energy savings policies and programs. The latter are comprised of measures such as standards and labels; better information to end-users, landlords, and builders; utility programs such as rebates; and individual metering. In the household sector, minimum energy performance standards have played a key role in reducing appliance and building energy use. Future savings potential through facilitating pass-through of expenditures on higher priced, high efficiency equipment in rental properties or other policies and programs, is therefore less than might have been the case otherwise.

Methodology and Data

US Residential Energy Use

According to the Residential Energy Consumption Survey (RECS) 2001, U.S. households used 9.86 quadrillion British thermal units (Btu) or 9.84 exajoules (EJ) of site energy.[4] (U.S. EIA 2004) The distribution of site and primary energy by end use is shown in

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[1] Throughout this article, when we refer to "energy efficient" equipment choices, we mean "cost-effective energy efficient" from the perspective of the purchaser's private cost. It should also be understood that we are referring to equipment that provides comparable levels of service, not simply equipment that consumes less energy.

[2] See Levinson and Neimann (2004) for an analysis of energy consumption when space heating is included in rent.

[3] Results from this study are also included in *Mind the Gap* (IEA 2007), which includes similar studies in other countries.

[4] One quadrillion (10^{15}) Btu equals 1.055 exajoules (10^{18} joules). Because energy figures are given in gross calorific values (GCV) in the U.S. and net calorific values (NCV) in most other countries, a correction must be made to the

Table 1. Space heating is by far the largest single end use of site energy, accounting for nearly half of all energy consumed in 2001. Together, the four end uses, space heating, refrigerators, water heating, and lighting, accounted for nearly 73% of residential site energy consumption and 59% of residential primary energy consumption.

Table 1. Site and Primary Energy Use, 2001

End Use	Site Energy			Primary Energy		
	QBtu	QBtu Share	Exajoules	QBtu	QBtu Share	Exajoules
Space Heating	4.62	46.9%	4.47	5.38	30.6%	5.31
Water Heating	1.68	17.1%	1.65	2.39	13.6%	2.32
Refrigerators	0.53	5.4%	0.56	1.56	8.9%	1.56
Lighting	0.34	3.5%	0.36	1.01	5.7%	1.00
Air Conditioning	0.62	6.3%	0.65	1.86	10.6%	1.80
Appliances & Misc	2.06	20.9%	2.17	5.35	30.3%	5.11
Total	9.86	100%	9.84	17.6	100%	17.1

Sources: U.S. EIA 2004 and U.S. EIA 2005

Methodology Applied to the Principal-Agent Problem in Energy End-Use

In order to determine whether any particular end use is affected by the PA problem, three questions must be answered. First, who uses the device? Second, who selects the device? Third, who pays the energy cost? Theoretically, if the answer to these questions is not the same person or entity, a PA problem exists, albeit of two different types. If the person paying the utility bill is not the person using the device, the user may consume more energy services than if he were not shielded from the price of energy. Similarly, if the person paying for energy is not the person choosing the device, the buyer will generally choose among the cheapest, and often least efficient, options. Thus, the PA problem can arise from two kinds of split incentives, one concerning usage (demand for energy services) and the other concerning the technical efficiency of the end-use device.

For any given device, determining the cases involving a PA problem may be conceptualized as a two-by-two table that classifies the device according to the user's ability to choose the device and the user's responsibility for paying associated energy costs (Table 2).

There are two points to keep in mind about the PA classification matrix. One is that the numbers of households falling into each case depend on the end use. For example, an apartment dweller may not be able to choose her water heater but can choose the television. Assuming she pays for her energy usage, she would fall into Case N for televisions but Case E for water heaters. The second point is that the matrix describes a given set of households at one point in time. Housing units may move from one category to another over time. This often happens when a pre-installed device must be replaced. The homeowner may have had no choice when first buying the house but can choose the replacement unit when the original device fails. A housing unit can also move from one category to another if its tenancy status changes. This happens when a homeowner buys a new house and keeps possession of the first one to use as a rental property or when an apartment building is converted to condos.

In the residential sector, the user is the dwelling occupant. The box labeled "Case N" is primarily composed of households that are occupant-owned, e.g., single-family residences

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reported energy data to make them comparable to the système international units used elsewhere. The GCV to NCV factors are 1 for electricity, 0.95 for liquid fuels, and 0.9 for natural gas.

(SFRs) and condominiums. These residents generally choose their own appliances, furnaces, air conditioners, etc., although in new homes these items are often pre-installed and the residents do not choose until the originals are replaced. Newer occupant-owned households are placed in Case E with respect to pre-installed appliances until those appliances are replaced. Case E households are mostly composed of individually billed rental households and new occupant-owned houses for which the occupants did not select one or more energy-using appliances or features. Most occupants, whether owners or renters, pay their own utility bills, although a significant number of renters have some utilities included in their rent. These households fall into Case B and Case U. Most of these households are rental units, covered by Case U. The Case B units consist of a small number of condominiums where the cost of one or more fuels is included in a condo fee.

Table 2. Principal-Agent Classification of End Users for the Residential Sector

	Can Choose Device	**Cannot Choose Device**
Direct Energy Payment	Case N: No Problem	Case E: Efficiency Problem
Indirect Energy Payment[a]	Case B: Both Usage and Efficiency Problems	Case U: Usage Problem[b]

[a] Occupants pay the energy costs, but not directly commensurate with energy use. This may take the form of utilities included in rent or a separate, but flat, energy fee. Often, this is due to the presence of a master meter serving multiple housing units although a significant number of individually metered units also have utilities included in rent (Levinson and Niemann 2004).

[b] There may also be an efficiency problem if three parties are involved: one who chooses the device, one who pays the energy cost, and the end user.

When categorizing occupants, the line between those who can and cannot choose their own devices is not always perfectly clear. In practice, plumbers and contractors typically make the decision on what model water heater to install. Often, water heaters are replaced following a catastrophic failure. Homeowners may call no more than one or two plumbers and take whatever model that plumber happens to carry in stock. In a sense, a PA problem exists because the plumber could provide more efficient models to reduce the homeowner’s long-term costs but may have difficulty conveying the benefits of a more costly model that saves energy, particularly when the homeowner has very little time to consider options. Knowing that homeowners in this situation may not have the time to compare lifetime costs and benefits of various models, plumbers are probably more inclined to recommend the cheapest models available for emergency replacements. However, a conscientious homeowner may know that a water heater is nearing the end of its expected lifetime and do some prior research on the cost, efficiencies, and expected savings of available models of water heaters to be prepared for the failure of his water heater. Thus, for purposes of this study, replacements of water heaters by occupant-owners are classified as a Case E PA problem for some households and as a Case N for others, based on an assumed rate of emergency replacements.

We follow a three-step procedure for calculating the energy use associated with a PA problem for each type of end use. The three steps are:

1. Allocate all households to the four cases of the principal-agent typology using housing data (Table 2). The allocation depends on factors such as tenancy status, age, whether the end use feature is pre-installed, and whether energy costs are individually billed;
2. Within each case, disaggregate households by important end-use characteristics such as fuel or type of heating/cooling system;

3. Estimate energy use considering factors such as housing unit type (SFR, multi-family residence (MFR), mobile home) and end-use characteristics.

We followed a 5-step procedure for estimating annual energy savings. These were calculated for one year's worth of shipments of refrigerators and water heaters. The calculation of energy savings for space heating was not performed due to the complexity of the task since one must consider not only the furnace efficiency and usage but also the building shell design and performance. This was beyond the scope of the present study. Savings from overcoming PA problems for lighting were determined to be negligible because relatively little residential lighting is affected by PA problems. The steps were:

1. Estimate the number of devices shipped for SFRs and MFRs;
2. Estimate the shares of units destined for PA affected households within each housing unit type;
3. Estimate the difference between the average energy consumption of efficient devices versus standard devices;
4. Calculate the share of efficient devices shipped to non-PA affected households;
5. Apply the shares of efficient devices going to the non-PA affected units to the PA affected households to derive the expected savings.

Results

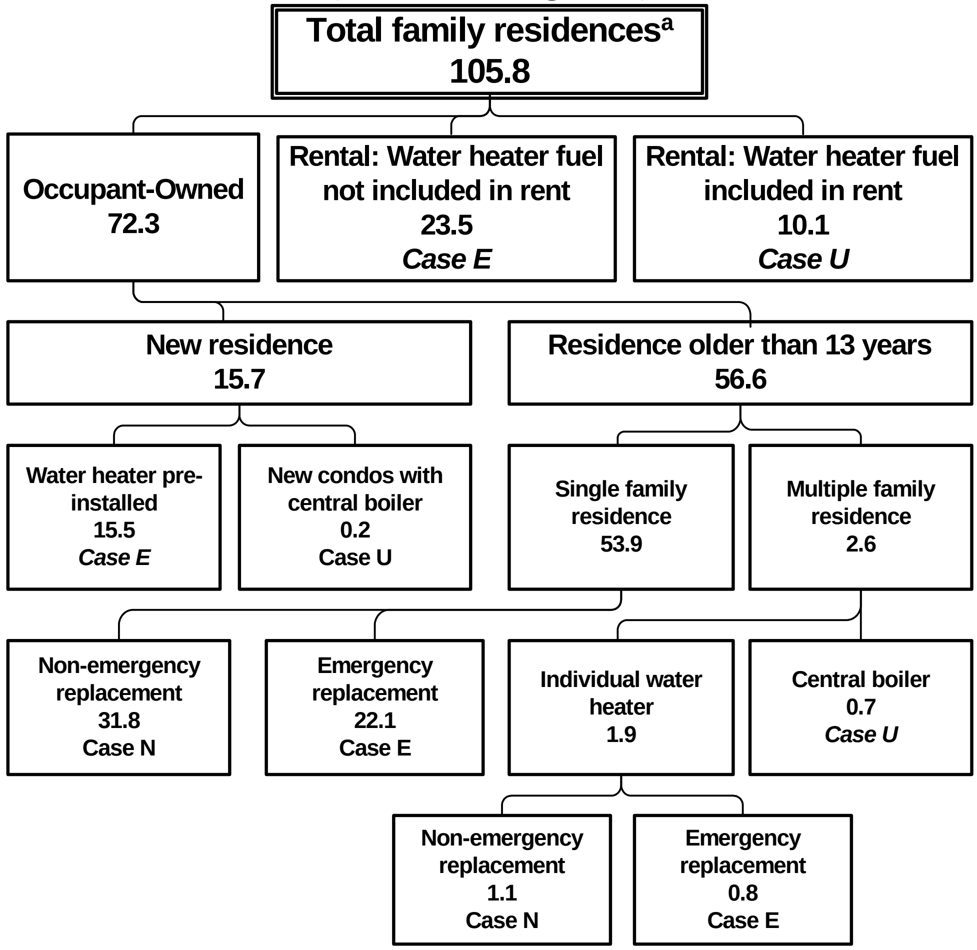
In this section, we describe the results of applying the above methodology for each of the four end uses. We present a complete analysis of one of the end uses – water heating. Results for the other three end uses are presented in the Summary and Conclusions section. A more complete analysis of the four end uses may be found in Murtishaw and Sathaye (2006), which also includes a sensitivity analysis and fuller description of the steps taken to calculate potential energy savings.

Description of the Principal-Agent Calculations for Water Heaters

The conceptual framework for determining the extent of the PA problem is the same as that shown in Table 2. Figure 1 demonstrates how the framework is applied in the case of residential water heating. The results of this application are described below and illustrated in Table 3, which aggregates the households in Figure 1 by case.

Data used for these calculations came from four different sources. Data on number of water heaters in the stock and their energy consumption are from the RECS 2001 (U.S. EIA 2004). Data on number of housing units by unit type, year of completion, and ownership status are from the American Housing Survey (AHS) (US Census Bureau 2005a). Statistics on whether utilities are included in rent are also taken from AHS. Figures on the number of single-family and multi-family housing units completed in 2003 with water heaters pre-installed were provided by the National Association of Home Builders (NAHB 2005). Data on water heater shipments and average shipment-weighted energy consumption were drawn from the Gas Appliance Manufacturers' Association 2005 (GAMA 2005).

Figure 1. Household Principal-Agent Characterization Diagram for Water Heaters (Million Housing Units)



[a] Numbers in parent categories will not always equal the sum of subordinate categories due to rounding.

Table 3. Water Heaters by Number and Share of Households and Site Energy

	Can Choose Device	**Cannot Choose Device**
Direct Energy Payment	Case N: 33.0 million [31%] 569 TBtu [34%], 552 PJ 59% of occupant-owned SFRs older than 13 years[a] 59% of occupant-owned MFRs, older than 13 years, w/ individual water heaters, utilities not included	Case E: 61.9 million [59%] 954 TBtu [57%], 925 PJ Most rental units Newer occupant-owned units 59% of occupant-owned units, older than 13 years, w/ individual water heaters
Indirect Energy Payment	Case B: Negligible Possibly a small number of condos older than 13 years w/ individual water heaters	Case U: 11.0 million [10%] 157 TBtu [9%], 152 PJ Significant number of rental units Condos with central boilers Newer condos with utilities included

[a] Assumes original water heater has been replaced by owner after 13 years, its estimated average lifetime.

For water heaters, we found no data on the proportion of new home buyers who actively choose their own water heaters. For purposes of allocating households into the various cases, we assumed that new home buyers never select their own water heaters. Occupant-owners who replace their own water heaters often do so on an emergency basis. Data from a KEMA study show that water heaters were replaced due to sudden failure 41% of the time (KEMA Inc. 2005). This leaves an estimated 59% of older occupant-owned units where owners can actively choose their own replacement water heaters as the only category of end users not affected by a PA problem. The exceptions are older condo units whose buildings use central boilers to supply hot water (Case U) and older condo units with individual water heaters whose water heating fuel is included in condo fees (Case B).

Case N. The average lifespan of a water heater is approximately thirteen years. In order to calculate the number of units with no PA problem (Case N), the occupant-owned SFRs (including mobile homes) where the water heater has been replaced at least once were estimated by subtracting the number of occupant-owned SFR units constructed between 1990 and 2003 (estimated from AHS data – 95% of all occupant-owned units constructed in that period) from the total number of occupant-owned SFRs. Then, 59% of this difference results in 31.8 million SFR and mobile home households in Case N with no PA problem (Figure 1). In order to determine which occupant-owned MFR units have no PA problem, older condos with central boilers or with the water heating fuel included in fees are subtracted from the set of older condos. Data limitations in the AHS tables did not allow a cross-tabulation of condominiums by water heater fuel and fuel types included in fees. However, 0.9 million occupant-owned MFR units are listed as having a steam or hot water heating system (U.S. Census Bureau 2005a). Adjusting for the number of those that are greater than thirteen years old leaves 0.7 million units. Subtracting this number from all older occupant-owned MFRs and multiplying by 59% places another 1.1 million households in Case N for a total of 33.0 million Case N households.[5]

Cases E, B & U. Case E consists of most rental units, all newer occupant-owned residences, and 41% of older occupant-owned residences. We assume that new home or condo buyers rarely specify the model of water heater to be installed. The AHS data indicate 15.7 million occupant-owned residences were completed between 1990 and 2003. From these we subtracted the 0.19 million newer condos that have central steam heating systems, which we assume also provides hot water. These were moved from Case E to Case U since units with centrally heated water will not be billed individually for the water heating fuel. The 0.68 million older condos with central steam or hot water systems also fall into Case U.

For older occupant-owned residences where the water heater has been replaced at least once, but the occupant did not choose the water heater because of a catastrophic failure of the water heater, 41% of the older SFR and mobile home stock yields 22.1 million households in Case E. To calculate the condo units that fall into Case E, the number of older units was adjusted by the estimated units with central water heating. Of those 1.9 million households, 0.8 million are assigned to Case E.

In addition to a large portion of occupant-owned units, we include all rental units in Case E, except those where the water heating fuel is included in rent, which fall in to Case U. Since the AHS data only indicate the number of housing units for which a given fuel's cost is included in rent or other fees, some assumptions were necessary in order to estimate the number of households whose water heating fuel is included in rent or fees. Using the ratio of electric water heating units among all water heating units in the entire rental stock, we allocated the rental units with electricity included in rent to households assumed to use electricity as water heating fuel.

[5] The total is slightly higher due to rounding.

For the number of rental units listed as having natural gas or fuel oil included in rent or fees, we assumed that all of these units have water heating by those fuels since these fuels are generally used for both space and water heating when available. Of the 33.6 million rental units, we estimate 11.0 million fall into Case U, and the remaining 23.5 fall into Case E. Due to data constraints we did not calculate households belonging to Case B, but the number of instances would be negligible.

Affected number of total households and their energy consumption. In order to calculate the energy consumed for water heating by the 72.9 million households that are affected by the PA problem, the total number of affected units was disaggregated by household type using the AHS data. This was necessary because average energy consumption for water heating varies by unit type. According to RECS, the energy used for water heating varies from 10 million Btu in households in MFR buildings with 5 or more units to 17.9 million Btu in SFRs (U.S. EIA 2004). Averages for smaller MFR buildings and mobile homes were in between. Multiplying the number of households by the RECS average water heating energy consumption for each household unit type yields an estimate of 1,111 trillion Btu of site energy associated with the PA problem.[6]

Estimating total primary energy associated with the PA problem required additional steps in order to produce a separate estimate of the share of electricity in the total energy associated with PA problems. RECS figures on total consumption by household by fuel and household type were apportioned to units on the basis of the shares of each type of housing unit affected by the PA problem. For example, 44.8 million of 74.0 million (non-mobile) SFR households were determined to be affected by the PA problem for water heaters. Total natural gas consumed for water heating in SFRs was 930 trillion Btu so roughly 61% (44.8 million divided by 74.0 million) of the natural gas consumed for water heating is estimated to occur in PA affected SFRs. Continuing this calculation for the other fuels and household types results in 863 trillion Btu of direct fossil fuel combustion and 234 trillion Btu (69.2 billion kWh) of electricity. This is roughly 66% of the 1,680 trillion Btu RECS shows for total water heater site energy and 11% of total residential site energy consumption. Multiplying the total for electricity by the primary energy factor (see Murtishaw and Sathaye 2006) yields 813 trillion Btu of primary energy for electricity for a total of 1,561 trillion Btu of primary energy or 8.4% of total residential primary energy.

Energy savings. We estimated annual savings from hypothetically eliminating the PA problem for one year's worth of water heater sales. Data from the Gas Appliance Manufacturers' Association show that 9.55 million water heaters were shipped in the U.S. in 2003 (GAMA 2005). A small number of LPG and fuel oil water heaters are sold, but GAMA does not supply data on them. Among gas and electric water heaters, 54% were gas.

The Census data on housing completions allowed us to determine how many water heaters were needed for new SFRs (1.3 million), MFRs (0.3 million), and mobile homes (0.07 million) (U.S. Census Bureau 2005b, U.S. Census Bureau 2005c). This leaves 7.9 million water heaters purchased as replacements. Of these, we assume that 41% were purchased as emergency replacements. Since we did not have data on main water heating fuel by year of completion, the 2003 total shares of gas and electric water heaters were applied to each category of housing type.

[6] This estimate is conservative to the extent that the presence of a PA problem causes energy consumption in PA affected households to be higher than the average.

Replacement water heaters were allocated to rental units by housing unit type on the basis of the share of each rental housing unit type in the total stock. For example, since rental MFRs constitute 20% of the total housing stock, 20% of the replacement water heaters purchased were assumed to be for rental MFRs. Altogether, an estimated 3.4 million gas water heaters and 3.0 million electric water heaters shipped in 2003 (67% of all water heaters shipped that year) were subject to PA problems.

With RECS data on average water heating consumption by housing unit type and fuel (adjusted to assign minimum efficiency to the PA-affected water heaters on the assumption that relatively few of the more efficient water heaters were purchased for households affected by PA problems), we find that 66 trillion Btu of natural gas and 25 trillion Btu of electricity (141 trillion Btu of total primary energy) will be consumed by these water heaters each year. Using data from the Technical Support Document for the water heater standards enacted in 2001 on the shipments of water heaters by efficiency level for each fuel, we estimated the average efficiencies of water heaters shipped to PA and non-PA affected households (U.S. DOE 2000). Applying the average efficiency of non-PA affected water heaters to the 67% of affected water heaters yields an estimated annual savings from 2003 sales of water heaters of 4.6 trillion Btu of site energy and 5.9 trillion Btu of primary energy.

Discussion

One aspect of the PA problem that warrants further consideration is the role of information in relation to PA problems. In some cases, incentives are not fundamentally misaligned but are misaligned in practice due to information barriers. In our results we have not attempted to account for “excess” energy consumption that is primarily associated with information problems.

In the Case E subset of our PA categorization, the problem is thought to occur because home builders and rental unit owners assume that occupants are unaware of or less sensitive to household operating costs than to the purchase or rental price. In order to recoup the cost of any energy efficient equipment that is more expensive than standard equipment, buyers or tenants will have to be convinced that higher housing costs will be recovered through energy savings. However, obtaining all of the information necessary and performing the calculations to verify the financial advantages of energy efficient equipment are daunting tasks for the prospective occupant. The better the information available, the less a PA problem truly exists. Many programs address information barriers for the end-uses covered in this study: appliance labeling, Energy Star, the Home Energy Rating System, and energy-efficient mortgages.

Summary

A summary of the total energy use and energy use associated with PA problems of the residential end-uses examined is shown in Table 4. Space heating accounts for the largest share (31%) of primary energy use as seen in Table 1 and from the Table 4 it is apparent that nearly two-thirds of its use is associated with PA problems. Associated energy consumption by water heaters and refrigerators is also significant. Together, the primary energy use associated with PA problems of these three end uses and lighting totals roughly 25.8% of primary residential energy use. The large share of energy associated with PA problems highlights the importance of standards for reducing energy consumption for these and other end uses where purchase decisions will be relatively unresponsive to information-based policies and programs.

Table 4. Residential Energy Use Associated with the Principal-Agent Problem

	Refrigera-tors	Water Heating	Space Heating	Lighting	Total, TBtu
Site Energy by End Use, TBtu (PJ)	532 (562)	1,680 (1,650)	4,657 (4,465)	343 (360)	7,212
Associated Energy and Shares:					
Site Energy, TBtu (PJ)	134 (141)	1,111 (1,076)	2,210 (2,143)	7.8 (8.2)	3,463
Share of Site Energy Use	25.2%	66.1%	47.5%	2.3%	48.0%
Share of Total Residential Site	1.4%	11.3%	22.4%	0.1%	35.1%
Primary Energy by End Use, TBtu (PJ)	1,560 (1,556)	2,390 (2,320)	5,375 (5,313)	1,007 (1,002)	10,332
Associated Energy and Shares:					
Primary Energy, TBtu (PJ)	394 (392)	1,561 (1,519)	2,570 (2,490)	23 (23)	4,548
Share of Primary Energy Use	25.2%	65.4%	47.8%	2.3%	44.0%
Share of Total Residential Primary	2.2%	8.9%	14.6%	0.1%	25.8%
Estimated Primary Annual Energy Savings Based on 2003 Sales	0.48 (0.48)	5.89 (5.69)	N/A	N/A	6.37

Note: Above results are based on 2001 energy use as applied to 2003 household shares. Annual energy savings are based on 2003 sales. Residential total site energy was 9,860 trillion Btu (9,840 PJ) and residential total primary energy was 17, 600 trillion Btu (17,100 PJ)

The estimated annual savings from the removal of the PA problem from one year's worth of sales are disproportionately larger for water heaters, 5.9 primary trillion Btu/year, than for refrigerators, 0.5 primary trillion Btu/year. The larger value for water heater savings arises due to several factors. First, the per unit energy consumption of refrigerators is much lower than water heaters. Second, with the introduction of a new, significantly more efficient refrigerator standard in 2001, the 2003 average energy efficiency for refrigerators meant that there was less energy to save than for water heaters. With the introduction of new water heater standards in 2004, a savings calculation based on the average 2004 water heater would also yield a smaller estimate of savings (50% or less although still higher than refrigerators). Third, a greater share of water heaters sold each year is destined for housing units affected by PA problems (67% compared to 32%).

Due to the complexity of calculating the savings potential for space heating and the limited scope of this study, no estimate of its potential was made. For lighting, the savings due to eliminating PA barriers would be negligible since information barriers play a much larger role in suppressing sales of efficient bulbs, as evidenced by the low penetration of CFLs in non-affected households.

Conclusions

Our analysis reveals several important findings. If the PA problem represents a significant barrier to efficiency, price signals alone may have a limited effect on inducing energy conservation in the residential sector because a large share of energy is consumed by end users who either have little or no control over the efficiency of energy-using equipment (Case E) or who are shielded to some extent from the costs of their energy consumption (Cases B and U). Table 5 highlights the fact that a large share of energy use falls into these categories.

The bulk of the PA-affected energy is characterized by Case E. Programs oriented toward the provision of information could overcome these barriers to some extent. Energy Star and Home Energy Rating System ratings for new homes, in addition to appliance labels, may help convince home builders that buyers will pay more attention to efficiency and enable them to pass through costs for better equipment. Appliance standards and building codes offer one way to address the PA barriers in both rental and occupant-owned housing markets. Information programs may then be used to induce savings beyond minimum standards.

Table 5. Summary of Shares of Site Energy by End Use Affected by Principal-Agent Problems

Case N: No PA Problem	**Case E: Efficiency Problem**
Refrigerators: 72% Water Heaters: 31% Space Heating: 53%	Refrigerators: 25% Water Heaters: 59% Space Heating: 40%
Case B: Usage and Efficiency Problem	**Case U: Usage Problem**
Refrigerators: <1% Water Heaters: negligible Space Heating: negligible	Refrigerators: 3% [a] Water Heaters: 10% Space Heating: 8%

[a] Refrigerators are an exception since no usage problem exists in Case U, assuming same agent (e.g. landlord) chooses the device and pays for energy.

Among the end uses we examined, the associated energy use for water heating and space heating accounts for almost 30% of all residential site energy (see Table 4). These end uses may deserve particular attention for overcoming PA barriers. For example, one study on an energy-efficiency design assistance program found that the program had very little success convincing developers of new MFR units to install gas-fired forced air or hydronic heating rather than electric baseboard systems because developers did not think they could pass the costs through to new tenants (Kelsey and Vance 2002). This provides evidence of the effect of PA barriers on fuel choice and primary energy efficiency.

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