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Chapter Author(s): Lucas W. Davis

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Evaluating the Slow Adoption of Energy Efficient Investments
Are Renters Less Likely to Have Energy Efficient Appliances?

Lucas W. Davis

19.1 Introduction

While public discussion of H.R. 2454 (the Waxman-Markey Bill) has focused on the cap-and-trade program that would be established for carbon emissions, the bill also includes provisions that would tighten energy efficiency standards for consumer appliances. Appliance standards have been used in the United States since the 1970s, and currently standards are in place for dozens of different appliance types. There is an important trade-off inherent with standards. A standard truncates the market, removing goods that are preferred by some buyers. This cost must be balanced against potential benefits. In particular, supporters of standards argue that they help address a number of market failures that would not be addressed by a cap-and-trade program alone.

One frequently discussed example is the landlord-tenant problem. Many studies have pointed out that landlords may buy cheap inefficient appliances when their tenants pay the utility bill. Although investments in energy efficient appliances could, in theory, be passed on in the form of higher rents, it may be difficult for landlords to effectively convey information about

Lucas W. Davis is assistant professor of economic analysis and policy at the Haas School of Business, University of California, Berkeley; a faculty affiliate at the Energy Institute at Haas; and a faculty research fellow of the National Bureau of Economic Research.

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the efficiency characteristics of appliances. Landlords have an incentive to inform tenants about energy efficient appliances. However, it may be difficult for tenants to evaluate these claims because most tenants are not experienced in evaluating the energy efficiency of appliances. Moreover, old energy bills are typically of limited value in evaluating claims from landlords because appliance utilization varies across households.

The landlord-tenant problem and other principal-agent problems are important to consider when designing carbon policy. Cap-and-trade programs work by increasing the price of energy, causing agents to internalize the social damages from their choices. Principal-agent problems reduce the effectiveness of this approach because the person experiencing these increased prices may not be the same person who is making decisions about energy use. For example, landlords may continue to purchase inefficient appliances even as their tenants' energy bills increase. In short, it may not be enough to simply put a price on carbon and the presence of principal-agent problems in addition to environmental externalities may justify combining appliance standards with cap and trade.

The landlord-tenant problem has been widely discussed in the literature (see, e.g., Blumstein, Krieg, and Schipper 1980; Fisher and Rothkopf 1989; Jaffe and Stavins 1994; Nadel 2002; and Gillingham, Newell, and Palmer 2009), but its practical importance has yet to be determined empirically. Understanding the mechanisms that explain this behavior and the magnitude of the distortion is important for determining how to most effectively target policies.

This chapter compares appliance ownership patterns between homeowners and renters using household-level data from a nationally representative survey, the Residential Energy Consumption Survey. The results show that renters are significantly less likely to report having energy efficient refrigerators, clothes washers, and dishwashers. Differences are large in magnitude and remain after controlling for household income, demographics, energy prices, weather, and other controls. The results imply nationwide an annual increase in energy consumption of approximately nine trillion btus, equivalent to 165,000 tons of carbon emissions annually.

The chapter focuses on a set of appliances that together represent about one-fourth of energy consumption in rental housing units.[1] There is reason to believe, however, that the other three-fourths (mostly heating and cooling) is also subject to the landlord-tenant problem. The agency issues with building energy efficiency may actually be worse than with appliances. Although it is relatively easy to verify that a dishwasher is energy efficient, it requires considerably more expertise to verify investments in, for example, roof insulation or heating and cooling ductwork. Given pending legislation

1. See U.S. Department of Energy (DOE), 2005 Residential Energy Consumption Survey, "Total Energy Consumption, Expenditures, and Intensities," table US12.

aimed at weatherization, an important priority for future work is to examine directly this broader class of energy efficient investments.

The chapter proceeds as follows. Section 19.2 provides relevant background information about energy efficiency standards in the United States and describes the data. Section 19.3 describes the estimating equation used to test for differences in appliance ownership patterns between homeowners and renters. Results are presented and discussed. Section 19.4 calculates the total energy consumption, expenditure, and carbon emissions implied by the estimates, and section 19.5 concludes.

19.2 Background and Data

Under the Energy Policy and Conservation Act of 1975 the U.S. Department of Energy (DOE) is required to establish energy efficiency standards for refrigerators, room air conditioners, clothes washers, dishwashers, and a broad class of additional residential appliances. Standards are periodically revised as warranted by technological improvements. Most recently, the Energy Policy Act of 2005, the Energy Independence and Security Act of 2007, and H.R. 2454 (the Waxman-Markey Bill) include provisions regarding energy efficiency standards for residential appliances.[2]

Since 1992, the Department of Energy in cooperation with the Environmental Protection Agency has, in addition, maintained a set of more stringent standards called "Energy Star" standards. Appliances exceeding these standards are among the most energy efficient in a particular class and receive an Energy Star label that is prominently displayed on the appliance at the time of purchase. Participation in the Energy Star program is voluntary though in practice all appliance manufacturers choose to participate. Similar programs are used in Australia, Canada, Japan, New Zealand, Taiwan, and the European Union. In addition, many utilities offer rebates for households that purchase Energy Star appliances, and the DOE recently committed $300 million in funding for rebates for qualified Energy Star appliances.[3]

This chapter examines the saturation of Energy Star appliances using household-level data from the 2005 Residential Energy Consumption Survey (RECS), a nationally representative in-home survey conducted approximately every five years by the DOE. The RECS provides detailed information about the appliances used in the home as well as information about the demographic characteristics of the household, the housing unit itself, weather characteristics, and energy prices. In addition, RECS reports state

2. See Nadel (2002) and US Department of Energy (2009), "Code of Federal Regulations, Energy Conservation Program for Consumer Products, Energy and Water Conservation Standards and Their Effective Dates, 430.32" for more information about appliance efficiency standards in the United States.

3. See Department of Energy, "Secretary Chu Announces Nearly $300 Million Rebate Program to Encourage Purchases of energy efficient Appliances," Press Release, July 14, 2009.

of residence for households living in New York, California, Florida, and Texas, and census division for all other households. The RECS is a national area-probability sample survey, and RECS sampling weights are used throughout the analysis.

The RECS also provides detailed information on who pays for utilities. The main results exclude households whose utilities are included in the rent. In the 2005 RECS sample, this includes 13.4 percent of all renters (4.2 percent of all households). These households do not pay directly for energy and, thus, tend to use their appliances more intensively.[4] In addition, the incentives for the adoption of energy efficient technologies are very different. Paying utilities themselves, landlords in these housing units have more incentive to invest in energy efficient appliances.

Beginning in 2005, households in the RECS were asked whether their major appliances were Energy Star.[5] These questions are somewhat unusual. Although many surveys ask about appliance ownership (e.g., American Community Survey), nationally representative surveys typically do not elicit information about energy efficiency. The question was asked for refrigerators, dishwashers, room air conditioners, and clothes washers, and households were shown an Energy Star label when answering the question. Households with appliances more than ten years old were assumed not to have Energy Star appliances and were not asked the question.

With any self-reported information, there is reason to be concerned about accuracy.[6] Perhaps most problematic for this analysis, it would seem reasonable to believe that homeowners may be better informed than renters about whether their appliances are Energy Star. This could provide an alternative explanation for the finding that homeowners are more likely to report having Energy Star appliances. In light of these concerns, the following analysis also examines two alternative measures of energy efficiency. Results are

4. Levinson and Niemann (2004) use RECS data to test whether energy use is higher in apartments where utilities are included in the rent. Controlling for observable characteristics of households, they find that tenants in apartments where utilities are included set their thermostats between one and three degrees (Fahrenheit) warmer during winter months when they are not at home.

5. Earlier RECS surveys do not ask about appliance energy efficiency. The 2001 RECS does include a question about whether your clothes washer is front loading or top loading. However, in 2001, front loading clothes washers were still relatively unusual in the United States, representing only 3.0 percent of all clothes washers in the RECS sample. See DOE, "2001 Residential Energy Consumption Survey: Housing Characteristics Tables," table HC5-4a.

6. The fraction Energy Star in the RECS corresponds poorly to fraction Energy Star in appliance sales data from DOE. For example, in the RECS among households with appliances less than four years old, the percentage of households who report owning an Energy Star appliance is 58 percent for refrigerators, 63 percent for dishwashers, 30 percent for room air conditioners, and 59 percent for clothes washers. In contrast, the DOE reports that the percentage Energy Star among appliances sold in 2005 was 33 percent for refrigerators, 82 percent for dishwashers, 52 percent for room air conditioners, and 36 percent for clothes washers. These percentages are based on sales data reported to DOE by retail partners. The DOE warns users that the set of retail partners changes from year to year and urges caution in using these data, particularly for making comparisons across years.

generally similar for these alternative measures, suggesting that the results are not entirely driven by misreporting.

First, in addition to asking whether a household's clothes washer is Energy Star, RECS asks if the clothes washer is "front loading" or "top loading." As described in detail in Davis (2008), front-loading clothes washers tumble clothes on a horizontal axis through a pool of water at the bottom of the tub, using about 50 percent less energy per cycle than conventional washers. Thus, "front loading" is an excellent proxy for energy efficiency and, importantly, whether the clothes washer is front loading is likely to be salient to both homeowners and renters.

Second, results are reported for energy efficient lighting. After asking how many lights the household typically uses, the survey asks, "How many of these lights use energy efficient bulbs? An energy efficient bulb is a fluorescent tube or a compact fluorescent bulb that costs more than a regular bulb but is one that lasts much longer." The measure used in the analysis is whether the household reports having *any* energy efficient light bulbs though results are similar for the *percentage* of light bulbs that are energy efficient.

19.3 Results

19.3.1 Descriptive Statistics

Table 19.1 presents descriptive statistics. The first two columns report mean household characteristics for homeowners and renters. The final column reports *p*-values from tests that the means in the subsamples are equal. The table reveals pronounced differences between homeowners and renters. Homeowners have substantially higher annual household income, are less likely to receive welfare benefits, are older, are less likely to be nonwhite, and are more likely to live in suburban and rural areas. In addition, appliance saturation levels differ substantially with homeowners more likely to have clothes washers and dishwashers but less likely to have room air conditioners.

Energy efficient technologies are described near the bottom of table 19.1. Homeowners are significantly more likely to report having energy efficient refrigerators, dishwashers, clothes washers, and lighting. Differences range from 7 percentage points for refrigerators to 11 percentage points for clothes washers. Particularly striking are the means for front loading clothes washers. Nine percent of homeowners report having a front loading washer compared to only 2 percent for renters. For room air conditioners, the pattern is reversed, with more renters reporting Energy Star units. This primarily reflects the higher saturation levels of room air conditioners among renters. In addition, room air conditioners are somewhat different because they are often owned by renters. Whereas it would be unusual for a tenant to install

Table 19.1 **Comparing mean household characteristics of homeowners and renters**

	Homeowners	Renters	*p*-value
Household economic characteristics			
Household annual income (1000s)	55.7	34.2	.00
Proportion household head employed	0.90	0.88	.08
Proportion welfare	0.06	0.24	.00
Household demographics			
Household size (persons)	2.60	2.57	.69
Age of household head	52.7	42.2	.00
Proportion with children	0.34	0.38	.10
Proportion household head nonwhite	0.21	0.44	.00
Type of neighborhood			
Urban	0.36	0.57	.00
Town	0.16	0.19	.14
Suburban	0.23	0.14	.00
Rural	0.25	0.10	.00
Climate and electricity prices			
Annual cooling degree days (1000s)	1.58	1.61	.64
Annual heating degree days (1000s)	4.15	3.82	.09
Electricity prices (cents per kwh)	10.3	11.1	.09
Appliance saturation			
Refrigerator	1.00	1.00	.95
Dishwasher	0.67	0.39	.00
Room air conditioner	0.21	0.38	.01
Clothes washer	0.95	0.57	.00
Energy efficient technologies			
Energy Star refrigerator	0.24	0.17	.00
Energy Star dishwasher	0.18	0.07	.00
Energy Star room air conditioner	0.04	0.05	.01
Energy Star clothes washer	0.23	0.12	.00
Front loading clothes washer	0.09	0.02	.00
Energy efficient lighting (any)	0.41	0.33	.01
Sample size	2,979	1,219	
Implied number of households (millions)	77.8	28.6	

Notes: This table describes households in the 2005 Residential Energy Consumption Survey (RECS). Means are computed using RECS sampling weights. The final column reports *p*-values (clustering by census division) from tests that the means in the subsamples are equal. Some households have more than one refrigerator or room air conditioner, and the table reports whether the most used unit is Energy Star. The survey questions about clothes washers are careful to exclude community clothes washers located in, for example, the basement or laundry room of an apartment building.

his or her own refrigerator or clothes washer in a rental unit, room air conditioners are relatively portable and can be easily installed.

Comparison of means provides an important baseline. However, it is difficult to draw strong conclusions on the basis of the evidence in table 19.1. Although the differences for energy efficient technologies are consistent with the landlord-tenant problem, this pattern could also be driven by other factors such as household income that are correlated with homeownership. The analysis that follows adopts a regression framework, comparing the saturation of energy efficient technologies between homeowners and renters while controlling for household income and other household characteristics. It is worth emphasizing that although the means for many of the characteristics are very different, there is a fair degree of overlap between homeowners and renters. Consider household income, for example. Although mean annual household income is very different ($55,700 for homeowners compared to $34,200 for renters) there are a reasonable number of renters (291 out of 1,219) with household income higher than the median household income for homeowners, and a reasonable number of homeowners (895 out of 2979) with household income lower than the median household income for renters. This lends credibility to the regression framework and its ability to effectively control for the observable differences between groups.

19.3.2 Regression Results

Table 19.2 presents estimates from a linear probability model of the following form,

$$y_i = \beta_0 + \beta_1 1(\text{renter}) + \beta_2 X_i + \varepsilon_i.$$

The dependent variable y_i is an indicator variable equal to one if the household reports having a particular energy efficient technology. For example, in the first row, the dependent variable is an indicator variable for households with an Energy Star refrigerator. The table reports the estimated coefficient and standard error corresponding to 1 (renter), an indicator variable for renters. The coefficient of interest β_1 is the difference in Energy Star appliance saturation between renters and homeowners with a negative coefficient indicating that renters are less likely to have an energy efficient model. Households who do not have a particular technology type are excluded from the regression, so the sample size varies across rows from 4,198 (all households) for lighting to 1,184 for room air conditioners.

Table 19.2 reports estimates of β_1 from four different specifications ranging from no controls in column (1) to the complete vector of covariates X_i in column (4) including household income (cubic), household demographics including indicators for whether the household head is employed and whether the household receives welfare benefits, indicator variables for 1, 2, 3, 4, 5, and 6+ household members, the age of the household head, and indicators for whether the household has children and whether the household head is nonwhite, as well as electricity prices (cubic), heating and cooling degree days (cubics), census division, and available state indicators. One of the important reasons why it is important to control for these household characteristics is that homeowners and renters may differ in the level of uti-

Table 19.2 **Are renters less likely to have energy efficient appliances?**

	(1)	(2)	(3)	(4)
Energy Star refrigerator [sample mean = .22]	–.067	–.034	–.056	–.067
	(.014)	(.017)	(.015)	(.015)
Energy Star dishwasher [sample mean = .25]	–.100	–.073	–.086	–.095
	(.024)	(.024)	(.033)	(.036)
Energy Star room air conditioner [sample mean = .16]	–.032	–.016	–.018	–.009
	(.011)	(.016)	(.016)	(.023)
Energy Star clothes washer [sample mean = .23]	–.030	–.002	–.027	–.033
	(.014)	(.016)	(.017)	(.014)
Front loading clothes washer [sample mean = .08]	–.054	–.032	–.028	–.031
	(.007)	(.004)	(.005)	(.005)
Energy efficient lighting [sample mean = .39]	–.075	–.038	–.046	–.049
	(.023)	(.026)	(.031)	(.024)
Household income (cubic)	No	Yes	Yes	Yes
Household demographics	No	No	Yes	Yes
Electricity prices (cubic)	No	No	No	Yes
Heating and cooling degree days (cubics)	No	No	No	Yes
Census division and available state indicators	No	No	No	Yes

Notes: This table reports estimated coefficients corresponding to an indicator for renter from twenty-four separate regressions, all estimated using least squares with RECS sampling weights. For each regression, the dependent variable is an indicator variable equal to one if the household has the energy efficient technology indicated in the row heading. Standard errors (in parentheses) are robust to heteroskedasticity and arbitrary correlation within census divisions.

lization of appliances. Households with high utilization levels have more to gain from adoption of energy efficient technologies (Hausman and Joskow 1982) because the savings are larger.

Consider first the estimates for refrigerators. In column (1) without controls, renters are 6.7 percentage points less likely to report having energy efficient refrigerators. This difference is identical to the difference in sample means in table 19.1. Controlling for household income decreases the point estimate corresponding to 1 (renter), consistent with high-income households being both more likely to be homeowners and more likely to own energy efficient refrigerators. Adding additional controls in columns (3) and (4) increases the point estimates to 5.6 and then back to 6.7 percentage points.

For dishwashers without controls, the difference is 10.0 percentage points. This is relatively large compared to the sample mean of 25 percent. As with refrigerators, the point estimate decreases after adding income and then increases again after adding additional controls. Homeowners tend to be older, face lower electricity prices, and live in rural and suburban areas, all characteristics that tend to decrease the probability that a household reports having energy efficient appliances.

Estimates for room air conditioners and clothes washers are also negative though consistently smaller than the coefficients for refrigerators and dishwashers. As mentioned in the preceding, room air conditioners are relatively portable, potentially mitigating the landlord-tenant problem. Point estimates for front loading clothes washers are negative, precisely estimated, and large relative to the sample mean of 8 percent. Finally, the estimate for lighting in the full specification is 4.9 percentage points, compared to the somewhat larger sample mean of 39 percent. With lighting, it is relatively easy for a tenant to move into a rental unit and replace incandescent light bulbs with energy efficient light bulbs. On the other hand, the cost savings from energy efficient lighting are accrued over many years, and there may be moving costs or other factors that prevent renters from taking energy efficient light bulbs with them when they move.

19.3.3 Discussion of Alternative Possible Explanations

These results demonstrate a consistent pattern of renters being less likely to report having energy efficient technologies. Although these results are consistent with the landlord-tenant problem, it is important to consider possible alternative explanations.

First, the differences could reflect landlords choosing not to invest in energy efficient technologies because appliances may have a shorter lifespan in renter occupied units. Because they do not own the appliances, renters may treat appliances more roughly (e.g., slamming doors, breaking refrigerator shelves), increasing the wear and tear on appliances eventually leading to them needing to be replaced. If this behavior is prevalent, landlords would then efficiently choose less expensive appliances. Similarly, landlords may be concerned about possible theft of appliances. This might be particularly problematic for lighting, with expensive light bulbs likely to disappear when renters move out.

Second, the differences could reflect unobserved differences between homeowners and renters in taste for green products. Suppose that, controlling for observables, homeowners receive a warm glow from using an energy efficient technology but renters do not. Alternatively, it could be that controlling for observables, homeowners have stronger tastes for certain appliance characteristics that are correlated with energy efficiency. These differences in taste could lead landlords to efficiently invest less in energy efficient technologies. For tastes to explain these findings, this preference for "green" would need to be imperfectly correlated with household income and other control variables and positively correlated with home ownership.

The following subsection reports the results from alternative specifications aimed at evaluating these and other possible alternative explanations. Many of these specifications add additional controls, and, for the most part, the basic pattern of renters being less likely to have energy efficient technologies is not sensitive to the addition of these controls. Although it is impossible to definitively rule out possible alternative explanations, the fact that the results are robust across alternative specifications lends support to the interpretation of these estimates as evidence of the landlord-tenant problem.

19.3.4 Alternative Specifications

Table 19.3 reports results from the baseline specification and thirteen alternative specifications. The dependent variable is indicated in the top of each column. For example, in column (1), the dependent variable is an indicator variable equal to one if the household has an Energy Star refrigerator. All specifications control for household income (cubic) and other household demographics, as well as electricity prices (cubic), heating and cooling degrees (cubics), census division, and available state indicators as in column (4) of table 19.2.

Row (A) reports the baseline specification. For row (B), the model is estimated using a logit model. Average marginal effects are reported and are very similar to the baseline estimates. Row (C) excludes households that "don't know" if their appliance is Energy Star. In the baseline specification, these households are treated as not having Energy Star appliances, and this choice does not seem to be driving the results. Relatively few households answer "don't know," and the fraction is similar for homeowners and renters. For example, for refrigerators, 4.0 percent of homeowners and 5.3 percent of renters answer "don't know."

Rows (D–F) restrict the sample to households with relatively new appliances. Again, results are similar to the baseline specification, suggesting that the results are not driven by differences in appliance age between homeowners and renters. If anything, the point estimates tend to grow larger (in absolute value) as one restricts the sample to relatively newer appliances.

Rows (G) and (H) report estimates separately for renters below and above the mean level of annual household income for renters. Estimated coefficients are similar for both groups and overwhelmingly negative, providing mild evidence against the "green tastes" explanation. If we thought that the results were driven by taste for green products that is imperfectly correlated with household income, one would have expected smaller estimated coefficients for high-income renters.

Row (I) reports estimates for renters whose utilities are included in the rent. Point estimates are negative and statistically significant for refrigerators, room air conditioners, and clothes washers. This is somewhat surprising because landlords in these units are paying utilities and, thus, have incentive to invest in energy efficiency. Still, it is important to keep in mind that these households are a somewhat unusual and unrepresentative group, overwhelmingly living in smaller apartments in older multiunit buildings. Those that do have refrigerators and clothes washers are more likely to have smaller apartment-sized models where energy efficiency options are more limited.

Row (J) restricts the sample to multiunit buildings and row (K) controls

Table 19.3 Are renters less likely to have energy efficient technologies? Alternative specifications

	Energy Star refrigerator [mean = .22] (1)	Energy Star dishwasher [mean = .25] (2)	Energy Star room air conditioner [mean = .16] (3)	Energy Star clothes washer [mean = .23] (4)	Front loading clothes washer [mean = .08] (5)	Energy efficient lighting [mean = .39] (6)
(A) Baseline specification	–.067	–.095	–.009	–.033	–.031	–.049
	(.015)	(.036)	(.023)	(.014)	(.005)	(.024)
(B) Logit model	–.071	–.103	–.011	–.033	–.044	–.050
	(.015)	(.038)	(.022)	(.016)	(.006)	(.025)
(C) Excluding "don't know"	–.071	–.106	–.014	–.040	n/a	n/a
	(.016)	(.037)	(.025)	(.016)		
(D) Among households with appliances < 10 years old	–.080	–.094	–.009	–.021	–.039	n/a
	(.020)	(.037)	(.037)	(.017)	(.011)	
(E) Among households with appliances < 5 years old	–.140	–.124	–.020	–.071	–.066	n/a
	(.029)	(.047)	(.049)	(.032)	(.017)	
(F) Among households with appliances < 2 years old	–.120	–.100	–.012	–.018	–.079	n/a
	(.037)	(.062)	(.019)	(.050)	(.033)	
(G) Low-income renters only	–.066	–.054	–.013	–.027	–.001	–.027
	(.021)	(.037)	(.021)	(.027)	(.013)	(.014)
(H) High-income renters only	–.047	–.102	.001	–.032	–.055	–.060
	(.027)	(.038)	(.027)	(.014)	(.013)	(.037)
(I) Renters with utilities included	–.074	.004	–.100	–.150	–.050	–.001
	(.018)	(.044)	(.036)	(.044)	(.011)	(.041)
(J) Among households living in multiunit buildings	–.064	–.041	–.006	–.074	–.032	–.026
	(.027)	(.083)	(.046)	(.108)	(.019)	(.055)
(K) Including housing characteristics	–.038	–.071	.005	–.033	–.031	–.040
	(.015)	(.042)	(.013)	(.012)	(.008)	(.028)
(L) Including self-reported utilization	n/a	–.095	–.009	–.031	–.031	–.045
		(.036)	(.023)	(.014)	(.005)	(.024)
(M) Excluding households who receive energy assistance	–.077	–.101	–.017	–.030	–.033	–.047
	(.017)	(.035)	(.023)	(.015)	(.005)	(.020)
(N) Excluding cities with rent control (NY, CA)	–.066	–.086	–.026	–.032	–.026	–.059
	(.017)	(.033)	(.031)	(.014)	(.005)	(.015)

Notes: This table reports estimated coefficients corresponding to an indicator for renter from seventy-nine separate regressions, all estimated using least squares with RECS sampling weights. For each regression, the dependent variable is an indicator variable equal to one if the household has the energy efficient technology indicated in the column heading. All specifications control for household income (cubic) and other household demographics, as well as electricity prices (cubic), heating and cooling degrees (cubics), census division, and available state indicators as in column (4) of table 19.2. Standard errors (in parentheses) are robust to heteroskedasticity and arbitrary correlation within census divisions.

for housing characteristics including the age of the housing unit, an indicator variable for multiunit, number of bedrooms, number of total rooms, and total square feet. These characteristics help proxy for lifetime wealth. Brueckner and Rosenthal (2009), for example, point out that newer houses tend to be owned by high-income households and that, over time, neighborhoods with an older housing stock tend to attract lower-income households. The point estimates are similar with these additional controls.

Row (L) controls for self-reported measures of utilization. For dishwashers and clothes washers, RECS asks households to report the number of loads a household typically does in a week. For air-conditioning and lighting, utilization is assessed by asking about the number of hours typically used per day. Adding the self-reported measures of utilization does little to the estimates. This is perhaps not surprising because the household characteristics already included in the regressions are important determinants of utilization levels. For the baseline specification, it is better to exclude these self-reported measures because utilization is a function of energy efficiency. As discussed in Davis (2008), energy efficient technologies lower the cost of utilization, potentially leading to increased utilization.

Row (M) excludes households who receive energy assistance. In the RECS, 4.4 percent of households receive some public aid. The largest such program, the Low Income Home Energy Assistance Program (LIHEAP) has been in operation in the United States since 1982 and operates in all fifty states with a $4.5 billion dollar budget in 2009. Eligible household must meet income requirements, and, typically, assistance is awarded on a first come, first served basis. For households facing subsidized electricity rates, it makes sense that landlords would not make costly investments in energy efficiency, and it is reassuring that the results do not change when excluding these households.

Finally, row (N) excludes households in urban areas in California and New York. Where the rental housing market is subject to rent control, landlords are constrained from making costly investments in energy efficiency because there is no scope for these investments to be capitalized into rents. Rent control is relatively uncommon in the United States, though several urban areas in California and New York have rent controls for some units, and it is interesting to see that the results do not change when households in these areas are excluded.

19.4 Evaluating the Implied Total Cost

An appealing feature of the estimates in section 19.3 is that they provide some of the information necessary to evaluate the overall magnitude of the landlord-tenant problem for an important group of household technologies. This section illustrates how these estimates can be applied, under simplified assumptions, to infer the implied total energy consumption, expenditure, and carbon emissions from the landlord-tenant problem. This preliminary assessment indicates that the total cost of this market failure is not negligible but that it is small relative to total energy consumption in rental housing units.

Table 19.4 reports the total cost of the landlord-tenant problem as implied by the estimates in the baseline specification. These results are calculated using average annual energy consumption and energy expenditure for Energy Star appliances from Sanchez et al. (2008).[7] The thought experiment is to consider how many additional energy efficient appliances there would be in the United States if renters were equally likely as homeowners to have these technologies.

The estimates imply that if renters were equally likely to have energy efficient appliances, in the United States there would be 2.2 million more Energy Star refrigerators, 3.1 million more Energy Star dishwashers, and 6.3 million more energy efficient light bulbs.[8] The estimates imply smaller impacts for room air conditioners and clothes washers. Nationwide, this would reduce annual energy consumption by 9.4 trillion btus, reduce annual energy expenditures by 93 million, and reduce annual carbon emissions by 166,000 tons.

To put this in perspective, this is about 1/2 of 1 percent of total energy consumption in rental housing units.[9] There are several reasons why this is not a larger fraction. First, in this thought experiment, the saturation of energy efficient technologies is increasing by only between 1 and 9 percentage points. Although not negligible, this is very different from assuming, for example, comprehensive replacement of all conventional appliances with energy efficient appliances. Second, these end-uses represent only about one-fourth of total energy expenditure in rental housing units.[10] Third, these calculations assume that energy efficient technologies use between 10 percent

7. Sanchez et al. (2008, table 5) reports annual energy savings per Energy Star unit of 0.85 Mbtu ($7.59) for refrigerators (15 percent), 1.17 Mbtu ($11.45) for dishwashers (29 percent), 0.68 Mbtu ($6.05) for room air conditioners (10 percent), and 1.32 Mbtu ($12.23) for clothes washers (20 percent). Sanchez et al. (2008, table 6) report that these appliances generate between .015 and .018 tons of carbon per Mbtu depending on the types of energy (electricity, natural gas, etc.) used by each appliance. Energy efficient light bulbs are assumed to use fifteen watts, compared to sixty watts for conventional incandescent bulbs.

8. In related work, Murtishaw and Sathaye (2006) use data from the American Housing Survey to evaluate the scope for principal-agent problems in residential refrigeration, water heating, space heating and lighting, concluding that 24 percent of residential energy consumption in the United States is potentially subject to principal-agent problems. This study was part of an international project whose results are described in International Energy Agency (2007).

9. According to DOE, "2005 Residential Energy Consumption Survey, Total Energy Consumption, Expenditures, and Intensities," table US1, rental housing units in the United States used 2.39 quadrillion btus of energy in 2005.

10. According to DOE, "2005 Residential Energy Consumption Survey, Total Energy Consumption, Expenditures, and Intensities," table US12, air conditioners, refrigerators, lighting, and other appliances together represent 36 percent of total energy consumption in rental housing units. Space and water heating represent the other 64 percent.

Table 19.4 The implied total cost of the landlord-tenant problem

	Refrigerators	Dishwashers	Room air conditioners	Clothes washers	Light bulbs	All technologies combined
Total units in millions	2.2	3.1	0.3	1.1	6.3	13.1
	(0.5)	(1.2)	(0.8)	(0.5)	(3.2)	(3.6)
Annual energy consumption in btus, trillions	1.9	3.7	0.2	1.4	2.1	9.4
	(0.4)	(1.4)	(0.5)	(0.6)	(1.1)	(2.1)
Annual expenditure on energy in 2009 dollars, millions	17.8	37.9	1.9	13.9	20.1	92.9
	(4.1)	(14.4)	(4.8)	(6.1)	(10.3)	(20.0)
Annual carbon emissions in metric tons, thousands	34.0	65.9	3.6	21.3	38.3	165.8
	(7.7)	(25.0)	(9.2)	(9.3)	(19.6)	(35.7)

Notes: This table reports the total cost of the landlord-tenant problem as implied by the estimated coefficients in column (4) of table 19.2. Standard errors (in parentheses) are robust to heteroskedasticity and arbitrary correlation within census divisions.

and 30 percent less energy than conventional technologies. The one exception is lighting, for which savings are larger.

19.5 Concluding Remarks

This chapter provides one of the first empirical analyses of the landlord-tenant problem. Across specifications, the estimates indicate that renters are significantly less likely to have energy efficient refrigerators, clothes washers, dishwashers, and lighting. Taken literally, the estimates imply nine trillion btus of excess energy consumption annually in the United States. More research and better data are needed to fully evaluate this problem. The new questions in the RECS are a step in the right direction, but more information is needed including results from professional energy audits to assess potential problems about the accuracy of the self-reported measures of energy efficiency. In future work, it would also be valuable to extend the analysis to a broader class of residential energy efficiency investments including building insulation, windows, and heating equipment.

References

Blumstein, Carl, Betsy Krieg, and Lee Schipper. 1980. "Overcoming Social and Institutional Barriers to Energy Conservation." *Energy* 5:355–71.

Brueckner, Jan, and Stuart Rosenthal. 2009. "Gentrification and Neighborhood Housing Cycles: Will America's Future Downtowns Be Rich?" *Review of Economics and Statistics* 91 (4): 725–43.

Davis, Lucas W. 2008. "Durable Goods and Residential Demand for Energy and Water: Evidence from a Field Trial." *RAND Journal of Economics* 39 (2): 530–46.

Fisher, Anthony C., and Michael H. Rothkopf. 1989. "Market Failure and Energy Policy: A Rationale for Selective Conservation." *Energy Policy* 17:397–406.

Gillingham, Kenneth, Richard Newell, and Karen Palmer. 2009. "Energy Efficiency Economics and Policy." *Annual Review of Resource Economics* 1:597–619.

Hausman, Jerry A., and Paul L. Joskow. 1982. "Evaluating the Costs and Benefits of Appliance Efficiency Standards." *American Economic Review* 72 (2): 220–25.

International Energy Agency. 2007. *Mind the Gap: Quantifying Principal-Agent Problems in Energy Efficiency.* Paris: OECD Publishing.

Jaffe, Adam B., and Robert N. Stavins. 1994. "The Energy Paradox and the Diffusion of Conservation Technology." *Resource and Energy Economics* 16:91–122.

Levinson, Arik, and Scott Niemann. 2004. "Energy Use By Apartment Tenants When Landlords Pay for Utilities." *Resource and Energy Economics* 26:51–75.

Murtishaw, Scott, and Jayant Sathaye. 2006. "Quantifying the Effect of the Principal-Agent Problem on U.S. Residential Energy Use." Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory Working Paper no. 59773.

Nadel, Steven. 2002. "Appliance and Equipment Efficiency Standards." *Annual Review of Energy and the Environment* 27:159–92.

Sanchez, Marla, Richard E. Brown, Gregory K. Homan, and Carrie A. Webber. 2008. "2008 Status Report: Savings Estimates for the Energy Star Voluntary Labeling Program." Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory Working Paper no. 56380.

Comment Olivier Deschênes

Most proposed climate legislations are centered on the establishment of a market-based mechanism to price the externality caused by carbon emissions. In many cases, these proposals also include other provisions such as industry-specific subsidies, standards, and other forms of regulations or incentives. The chapter by Lucas Davis begins by making the key observation that in settings where asymmetric information or principal-agent problems arise, carbon pricing alone may not be sufficient to solve the environmental externality problem. Such settings would justify combining standards and market-based approaches to address the externality, as is the case for example in H.R. 2454.

One example where a market failure still arises in the presence of a market price on carbon emissions is the "landlord-tenant" problem. Because information about the energy efficiency of certain appliances might be difficult to credibly convey to tenants, landlords will tend to furnish their rental units with cheaper, energy inefficient appliances. In that case, and to the extent that tenants cannot change their appliances in response to the higher energy costs, carbon pricing will lead to inefficient energy consumption amongst tenants. Lucas Davis's chapter fills an important gap in the literature by presenting the first comprehensive empirical analysis of the landlord-tenant problem using data from the 2005 Residential Energy Consumption Survey (RECS).

The evidence in this chapter clearly supports the notion of a landlord-tenant problem. First and foremost, Davis's analysis convincingly shows that renters are significantly less likely to have energy efficient appliances (defined as appliances with the "Energy Star" certification) than homeowners. This is especially notable for refrigerators and dishwashers, where the homeowner-renter energy efficiency gaps are 7 and 10 percentage points, respectively. The baseline coverage rate of these energy efficient appliances is roughly 25 percent so the estimated gaps are large. Importantly, most of the regression estimates reported are insensitive to the inclusion or exclusion of a rich set of control variables such as household income, demographic variables, energy prices, and weather variables. As such, concerns about omitted variables bias plaguing the estimates are unlikely to be important. Davis also

Olivier Deschênes is associate professor of economics at the University of California, Santa Barbara, and a research associate of the National Bureau of Economic Research.

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