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Residential Energy Efficiency and the Principal-Agent Problem

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ABSTRACT

Investments in residential energy-efficiency are associated with both positive externalities (reduced greenhouse gas emissions, reduced need for new power-generating capacity) and private cost savings. However, these investments lag far behind even those levels predicted by conventional cost-benefit analysis. This paper explores one potential explanation for this "efficiency gap" - the principal-agent (PA) problem as it applies to rental housing. I employ SAS® 9.3 to perform a logistic regression on data from the 2009 Residential Energy Consumption Survey and find that the PA problem is particularly pronounced in regards to weatherization improvements, a result that has implications for public policy.

Somewhat advanced SAS techniques were used to report the results of this regression in terms of marginal effects. A basic familiarity with statistical processes and microeconomic theory is useful in reviewing this paper.

INTRODUCTION

Residential energy efficiency is associated with a number of positive externalities, including reduced greenhouse gas emissions and a reduced need to construct new power generating capacity. Economic theory suggests that any technology associated with such externalities is likely to be characterized by underinvestment. However, adoption of residential energy efficiency has long lagged behind even those levels suggested by a simple analysis of private costs and benefits[1].

Among the reasons economists have offered to explain this "efficiency gap" is the principal-agent (PA) problem as it applies to rental housing. Where tenants are responsible for paying monthly utility bills, landlords may lack the appropriate incentive to invest in energy efficient technologies. Meanwhile, tenants may be reluctant to make costly investments when future residents are expected to reap many of the rewards.

While several researchers have attempted to quantify the effect of the principal-agent problem and incentive programs on the purchase of energy-saving technologies, the existing literature lacks insight into an important distinction between two types of energy-saving technologies. The first of these I will refer to as energy-saving "appliances." These are technologies -such as Energy Star certified refrigerators, clothes washers and dishwashers- for which the estimated energy savings do not vary with factors such as regional climate or the physical structure of a house. An Energy Star refrigerator installed in a 50 year-old, two-story house in Georgia will produce approximately the same amount of energy savings as the same refrigerator installed in a New England studio apartment. The second of these technologies I refer to as improvements in "weatherization." These include improved insulation, weather-stripping, and replacing doors and windows. The savings from these types of

1 See Daniel Yergen (1979) and Thomas Dietz (2010).

investments vary alongside climate and household characteristics.

The distinction between these two types of investments is important for two reasons: first, because the energy savings from weatherization improvements tend to far outweigh those from energy efficient appliances; and second, because energy efficient appliances are more conspicuous investments than weatherization improvements, and for that reason I hypothesize they are less likely to be impacted by the PA problem. Landlords may reasonably expect to enjoy a small rent premium from installing a new refrigerator or dishwasher, but they are unlikely to realize any of the benefits of new insulation.

This paper presents an empirical model designed to test this hypothesis. The paper is divided into five sections. The first contains a brief review of the existing literature. The second describes the model and the data to which it will be applied. The third describes the specific process used to conduct the analysis in SAS 9.3. The fourth discusses the empirical results. Some remarks about policy implications follow at the end.

LITERATURE REVIEW

Energy savings from weatherization improvements vary with local climate, but generally far exceed those of energy-efficient appliances. Damian Pitt et al (2012) estimate that the consistent application of an average weatherization upgrade could reduce residential energy use in Blacksburg, Virginia by approximately 36% in 2050. By contrast, appliances only account for approximately 30% of household energy consumption according to the Energy Information Administration (EIA)[2].

Investments in both kinds of energy-savings technologies have long lagged behind expected levels in the residential sector. One explanation for this perceived "efficiency gap" is the PA problem. Scott Murtishaw and Jayant Sathaye (2006) develop an econometric model to estimate the amount of energy savings that might be realized absent this problem. Their study considers data from the Residential Energy Consumption Survey (RECS) and compares energy saving investments in rental houses where tenants pay the utility bills to those in comparable owner-occupied properties. The authors estimate that if all households invested in energy-saving technologies at the same rate as owner-occupied households, the net energy savings would equal 3.4 trillion BTU, or 35% of the energy consumed by the US residential sector.

A contributing factor to the PA problem is asymetric information between landlords and tenants. Yvonne Phillips (2012) conducts a survey of homeowners and tenants regarding household insulation and energy saving investments in the Waikato region of New Zealand, a country the author describes as having poor home insulation by international standards. He finds that, on average, owner-occupiers are much better informed about their properties than either landlords or tenants. Tenants are the least well-informed of the three, as only 56% of them know whether or not their home has any ceiling insulation, as compared to 90% of all property owners. Phillips also finds that approximately half of all tenants described their house as too cold in the winter, while only 18% of landlords believed this was true of their properties. It seems unlikely that this problem is as pronounced for energy efficient appliances, as a new refrigerator proudly sporting the Energy Star label is far more

2 See http://www.eia.gov/consumption/residential/data/2005/c&e/summary/pdf/tableus12.pdf.

conspicuous than a ceiling crawlspace stuffed with the highest quality of insulation.

It seems reasonable to expect there should be a strong correlation between the determinants of investing in energy-efficient technologies and the determinants of high energy expenditures, as a primary motivation for making such investments is to save money on utility bills. Such factors may include both the physical characteristics of the property as well as the demographic characteristics of its occupants.

Dirk Brounen, Nils Kok and John M. Quigley (2012) develop a model to test the relative importance of these property and demographic characteristics in determining residential energy use. They find that physical characteristics are particularly strong determinants of demand for natural gas used for space heating while demographic characteristics are strong determinants of demand for electricity. These results seem intuitive, as preferences concerning optimal home heating vary relatively little while consumption of energy-intensive activities (video games, watching TV, surfing the internet, etc.) can vary dramatically between individuals.

Many of Brounen, Kok and Quigley's findings have been duplicated in the literature. Helena Meier and Katrin Rehdanz (2008) find that residential space heating expenditures in the United Kingdom increase alongside property size. Brian C. O'Neill and Belinda S. Chen (2002) find that per capita residential energy consumption increases with household income. David Ward et al. (2010) also find that high income households express a higher willingness-to-pay for Energy Star appliances, an indicator that they may also be more willing to invest in energy savings.

Bradford Mills and Joachim Schleich (2012) directly address the question of what factors influence the purchase of energy-saving technologies. They find that the age composition of household members is highly correlated with investments in energy saving technology, as households with young children are more likely to invest in such technology and households with elderly adults are less likely to do so.

A final factor that is expected to influence the purchase of energy-saving technologies is the receipt of assistance from public incentive programs. There is some debate over the efficacy of such programs, both in general and relative to one another. Unfortunately, relatively little empirical work has been done on this question. R.E. Pitts and J.L. Wittenbach (1981) employ a survey two years after the adoption of a new tax credit for insulation improvements and find that the credit had no effect on households' decision to weatherize. A more recent survey by Tingting Zhao et al (2012) finds that households cited tax credits as an important element in their decision to purchase weatherization improvements, suggesting that such programs may have become more effective in the three decades since Pitts and Wittenbach conducted their survey.

EMPIRICAL MODEL

I employed a logit model to determine the significance of various factors in influencing a household's decision to invest in energy-saving technologies. The dependent variable was dichotomous, equaling 1 when a household had invested in a relevant technology, and 0 when it had not. The independent variables included a number of property and demographic characteristics as well as the property's ownership status and several dummy variables representing the receipt of assistance from various incentive programs.

This model was applied to 6,513 residences from RECS 2009. Only single-family households were included in the sample, and all homes were constructed prior to the introduction of the first International Energy Conservation Code for the construction industry in 2000.

Two iterations of the model were tested. In the first, the dependent variable was called WEATHERIZATION, and equaled 1 whenever a household had invested in improved insulation or had installed new doors, windows or weather stripping. These investments are of particular interest to policymakers as they represent the largest source of potential energy savings in the residential sector. In the second iteration, the dependent variable was called APPLIANCES, and equaled 1 whenever a household had purchased one of the following: an Energy Star refrigerator, dishwasher, or clothes washer, energy efficient light bulbs, an energy-efficient freezer, or a water heater blanket.

The independent variables fall into four distinct categories. The first of these are property characteristics. These include STORIES, the number of stories a household has, and HOWOLD, the property's age at the time of the survey. The empirical literature shows that household energy expenditures increase along with property size and age, so it's expected that the higher the value of either variable, the more likely a household is to invest in energy-saving technologies. A final property characteristic was OWNED, which equaled 1 if a property is owner-occupied and 0 otherwise. As owner-occupied homes are unaffected by the PA problem, it is expected that they will be more likely to invest in energy-efficiency.

A second category of independent variables concerns incentive programs. This was a series of dummy variables that equaled 1 whenever a household had received any assistance from a relevant program. These included tax credits (TCREDIT), weatherization assistance programs (WEATHASST), subsidized loans (SLOAN), and rebates from either appliance manufacturers (MANREBATE) or utility providers (UREBATE). Receipt of assistance from any of these programs is expected to increase investment in energy-efficiency, though the type of investment made likely depends on a policy's particular structure as certain policies tend to finance only specific types of investments.

A third category of independent variables concerned household demographics. These included two measures of income: whether a household fell within 150% of the poverty line (POVERTY150) or earned more than $100,000 a year (WEALTHY). High-income households are expected to be more likely to invest in energy-efficiency as they tend to consume more energy. Another important factor indicated by the literature is household member age, and this was captured by two variables: the number of members under the age of 20 (CHILDREN) and the number over the age of 65 (ELDERLY). It was expected that households with children would be more likely to invest in energy-efficient appliances, as they tend to consume more electricity, while households with elderly members would be more likely to invest in weatherization improvements as they tend to consume more energy for space heating. Two final demographic variables measured whether the head of household has obtained at least a Bachelor's degree (COLLEGE) and whether they are a woman (FEMALE). There are conflicting theories about the effect of these variables. Brounen, Kok and Quigley (2012) find that female heads of households consume more natural gas, suggesting that they may benefit more from energy savings than their male counterparts, but Ward et al. (2010) find that female heads of households actually express a lower willingness-to-pay for Energy Star appliances. Mills and Schleich (2012) found that college educated households are more likely to invest in energy efficiency, perhaps because educational attainment is correlated with a low household discount rate, but Ward et. al (2010) found that households with a Bachelor's degree actually express a lower willingness-to-pay for Energy Star appliances.

Table 1: Descriptive Statistics

Variable	Mean	Std Dev.	CV	Min	Max	N
APPLIANCES	0.85	0.35	0.41	0	1	6513
WEATHERIZATION	0.7	0.46	0.65	0	1	6513
STORIES	1.4	0.53	0.38	1	4	6513
OWNED	0.86	0.34	0.4	0	1	6513
HOWOLD	44.38	22.48	0.51	11	89	6513
TCREDIT	0.07	0.26	3.63	0	1	6513
SLOAN	0	0.05	19	0	1	6513
MANREBATE	0.07	0.25	3.66	0	1	6513
UREBATE	0.07	0.25	3.67	0	1	6513
WEATHASST	0.02	0.13	7.81	0	1	6513
FEMALE	0.51	0.5	0.98	0	1	6513
COLLEGE	0.33	0.47	1.44	0	1	6513
NHSLDMEM	2.81	1.54	0.55	1	14	6513
POVERTY150	0.17	0.37	2.23	0	1	6513
WEALTHY	0.21	0.4	1.97	0	1	6513
CHILDREN	0.76	1.15	1.51	0	8	6513
ELDERLY	0.39	0.68	1.75	0	3	6513
NEWENGD	0.07	0.26	3.55	0	1	6513
MIDATLD	0.09	0.29	3.17	0	1	6513
ENCENTD	0.12	0.32	2.76	0	1	6513
SATLD	0.17	0.37	2.24	0	1	6513
ESCENTD	0.05	0.22	4.22	0	1	6513
WSCENTD	0.1	0.3	2.99	0	1	6513
MOUNTD	0.07	0.25	3.71	0	1	6513
PACD	0.17	0.37	2.25	0	1	6513

The final category of independent variables represents the property's geographic location. Regional effects are expected for two reasons: first, because energy prices vary by location, and second, because of variations in local climate. For instance, Helena Meier and Katrin Rehdanz (2008) find that space heating expenditures are positively correlated with heating degree days (HDDs), a standard measure of how frequently the temperature drops below levels that most people find comfortable. In this model, region was captured using a series of dummy variables representing the ten census districts. The base region was the West North Central Census Division, which had 6,837 HDD in 2009[3]. All other census districts had fewer HDDs in 2009, thus I expected that households in each of these regions will be somewhat less likely to invest in weatherization improvements than households in the base region.

Of particular interest to this study will be the differences between the estimated marginal effects for OWNED between the two regressions. Following Phillip's observation that both tenants and landlords tend to lack important information regarding

3 See http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0109

the quality of insulation in their properties, I expect that the PA effect will be more pronounced in the WEATHERIZATION regression than in the APPLIANCES regression.

Descriptive statistics for each of these dependent and independent variables are presented in **Table 1**. Of the 6,513 homes in my sample, 85% have invested in energy-efficient appliances and 70% have invested in weatherization improvements.

PERFORMING A LOGISTIC REGRESSION IN SAS

SAS has a built-in package for performing logit-style regressions. This method is ideal in many situations for estimating the influence of various factors on the value of a binomial dependent variable. The source code for my primary regression is reproduced below:

```
proc logistic data=paproblem outest=paproblem.r2 (RENAME=(stories =cfstories
    owned=cfownedhowold=cfhowold TCREDIT=cftcredit SLOAN=cfsloan
    WEATHASST=cfweathasst FEMALE=cffemale COLLEGE=cfcollege NHSLDMEM=cfnhsldmem
    POVERTY150=cfpoverty150 WEALTHY=cfwealthy CHILDREN=cfchildren ELDERLY=cfelderly
    NEWENGD=cfnewengd MIDATLD=cfmidatld ENCENTD=cfencentd SATLD=cfsatld
    ESCENTD=cfescentd WSCENTD=cfwscentd MOUNTD=cfmountd PACD=cfpacd)) descending;
model WEATHERIZATION = stories owned howold TCREDIT SLOAN WEATHASST FEMALE COLLEGE
    NHSLDMEM POVERTY150 WEALTHY CHILDREN ELDERLY NEWENGD MIDATLD ENCENTD SATLD
    ESCENTD WSCENTD MOUNTD PACD;
output out=paproblem.r3 xbeta=xb;
run;
```

One drawback of this approach is that the resulting coefficient estimates can be difficult to interpret. Technically speaking, they represent the change in the logit (or that natural log of the odds that y=1) for each unit change in the predictor, but rare indeed is the client (or, for that matter, the researcher!) with the ability to grasp this relationship intuitively. For this reason, it is common practice to transform these estimated coefficients into the associated “marginal effects” of each predictor on the dependent variable.

These can easily be calculated with the application of basic calculus. Marginal effects tell us the percentage change in the probability that y=1 for each unit change in a particular predictor. P.M. Wright helpfully outlined this approach in “Marginal Probabilities: An Intuitive Alternative to Logistic Regression Coefficients,”[4] and its specific application to this project is reproduced below.

```
data test.r4;
```

[4] Wright’s paper is available here: http://www.sascommunity.org/sugi/SUGI92/Sugi-92-235%20Wright.pdf

```
if _N_=1 then set test.r2;

set test.r3;

PPP=1/(1+EXP(-XB));

POWNED=1/(1+EXP(-(XB+CFOWNED)));

PMANREBATE=1/(1+EXP(-(XB+CFMANREBATE)));

MPMANREBATE=PMANREBATE-PPP;

…[repeat above through full set of independent variables]

run;
```

Table 2: Appliance Regression Results

Logistic regression				Number of observations	= 6513
				Wald ChiSq(22)	= 328.691
				Prob > ChiSq	= <.0001
				Likelihood Ratio	= 455.055

appliances	**Marginal Fx**	**Coefficient**	**Standard Error**	**Wald ChiSq**	**P>ChiSq**
owned	.0765***	0.8752	0.0941	86.5276	<.0001
stories	.0224***	0.2063	0.0809	6.4947	0.0108
howold	N/A	-0.00145	0.00175	0.6857	0.4076
tcredit	.1107***	0.5346	0.1973	7.3408	0.0067
sloan	N/A	0.9934	1.0396	0.9131	0.3393
manrebate	.1296***	1.6147	0.3105	27.0391	<.0001
urebate	.0523***	2.4234	0.4537	28.5301	<.0001
female	N/A	-0.0410	0.0737	0.3101	0.5776
college	.022**	0.2021	0.0894	5.1151	0.0237
nhsldmem	.0227***	0.2088	0.0463	20.3300	<.0001
wealthy	.0371***	0.3577	0.1225	8.5253	0.0035
poverty150	-.0525***	-0.4012	0.0939	18.2433	<.0001
elderly	N/A	-0.0764	0.0573	1.7792	0.1822
children	N/A	-0.0593	0.0635	0.8721	0.3504
newengd	.0602**	-0.0174	0.1778	0.0096	0.9219
midatld	N/A*	-0.2709	0.1508	3.2293	0.0723
encentd	N/A*	-0.2449	0.1340	3.3401	0.0676
satld	N/A	-0.0796	0.1249	0.4057	0.5242
escentd	N/A	0.0326	0.1732	0.0354	0.8507
wscentd	N/A	-0.0592	0.1401	0.1782	0.6730
mountd	N/A	0.0958	0.1760	0.2965	0.5861
pacd	.0383***	0.3708	0.1403	6.9799	0.0082
intercept	N/A	0.2090	0.1975	1.1197	0.2900

Notes: ***, **, * indicate statistically significant at the 1%, 5% and 10% level. Marginal probabilities only calculated for variables that were significant at the 5% level.

Table 3: Weatherization Regression Results

Logistic regression					
				Number of observations	= 6513
				Wald ChiSq(21)	= 710.939
				Prob > ChiSq	= <.0001
				Likelihood Ratio	= 906.520
weatherization	**Marginal Fx**	**Coefficient**	**Standard Error**	**Wald ChiSq**	**P>ChiSq**
owned	.1879***	1.3768	0.0835	272.1108	<.0001
stories	.0237**	0.1334	0.0616	4.6913	0.0303
howold	.0037***	0.0202	0.00150	182.0418	<.0001
tcredit	.1876***	1.3740	0.1751	61.5625	<.0001
weathasst	.2395***	2.1022	0.4357	23.2815	<.0001
sloan	N/A	0.8334	0.7728	1.1629	0.2809
female	N/A	-0.0907	0.0587	2.3851	0.1225
college	N/A*	0.1287	0.0677	3.6145	0.0573
nhsldmem	N/A	-0.0129	0.0349	0.1364	0.7119
wealthy	.0347**	0.1972	0.0821	5.7667	0.0163
poverty150	N/A	-0.1289	0.0831	2.4088	0.1207
elderly	.0395***	0.2259	0.0486	21.5925	<.0001
children	N/A	-0.0306	0.0469	0.4250	0.5144
newengd	.0602**	0.3527	0.1485	5.6386	0.0176
midatld	N/A	0.0885	0.1289	0.4711	0.4925
encentd	.0628***	0.3690	0.1204	9.3904	0.0022
satld	N/A*	-0.1655	0.0995	2.7671	0.0962
escentd	N/A	0.00233	0.1418	0.0003	0.9869
wscentd	N/A	-0.1314	0.1135	1.3399	0.2470
mountd	N/A*	-0.2318	0.1282	3.2716	0.0705
pacd	N/A	-0.1565	0.1012	2.3925	0.1219
intercept	N/A	-1.4428	0.1654	76.1249	<.0001

Notes: ***, **, * indicate statistically significant at the 1%, 5% and 10% level. Marginal probabilities only calculated for variables that were significant at the 5% level.

ANALYSIS OF RESULTS

The White Test and Durbin-Watson Test revealed no evidence of heteroschedasticity or serial correlation, respectively.

Tables 2 and 3 contain a summary of the regression results. Both models are statistically significant, as they both have model chi square statistics associated with their likelihood ratios that are significant at α=5%. Of the 23 independent variables tested, 10 proved at least marginally significant in the WEATHERIZATION regression (marginally significant defined here as α=10%) and 13 proved at least marginally significant in the APPLIANCES regression. Results for the statistically significant variables are reported as marginal effects.

STORIES was statistically significant in both regressions, but its marginal effect was quite small (~2%). This is likely because the variable is a poor proxy for the true factor of interest: property size. A two story house may be either massive or modest, and the literature suggests that houses on these two extremes will differ significantly in their propensity to invest in energy-saving technologies.

HOWOLD was a statistically significant factor for WEATHERIZATION but not for APPLIANCES. This is consistent with the literature, as Brounen, Kok and Quigley (2012) found that property age is a determinant of demand for natural gas (used primarily for space heating) but not for electricity. The effect, however, was small, with each additional decade of a property's age increasing its residents' likelihood to invest in weatherization by just less than 4%.

FEMALE was not statistically significant in either regression, and while COLLEGE was significant in the APPLIANCES regression, its marginal effect proved minimal. College graduates are just 2% more likely to purchase energy efficient appliances than their peers. These results may speak more to the quality of the data than the veracity of the literature, which has hypothesized a role for both factors. These two variables only record the gender and educational level of the survey respondent, and while it may be the case that the respondent is the functional “head of household” (as would be required to appropriately test the hypotheses advanced by Mills and Schleich (2012) and others), this is not guaranteed.

The number of household members and income appear to have little effect on the decision to invest in energy savings. NHSLDMEM was statistically significant for APPLIANCES but not for WEATHERIZATION. Each additional member increases a household's likelihood to invest in energy savings by approximately 2%. Likewise, POVERTY150 was statistically significant only for APPLIANCES (where a household that falls within 150% of the poverty line proved 5% less likely to invest in energy-efficient appliances, consistent with economic theory), but not for WEATHERIZATION. These results are consistent with Brounen, Kok and Quigley's (2012) findings that household demographics impact demand for electricity but not for natural gas. WEALTHY was statistically significant in both regressions, but contributes relatively little, with households that earn more than $100,000 a year only 3% more likely to invest in both kinds of energy-saving technologies.

More surprisingly, the ages of household members also appears to have little impact on investments in energy savings. CHILDREN was not statistically significant in either regression, and ELDERLY was significant only for WEATHERIZATION (where each additional household member above the age of 65 increased the likelihood of an investment by approximately 4%). The latter finding is consistent with the literature, as Brounen, Kok and Quigley (2012) find that elderly heads of households consume more natural gas than their peers, indicating that space heating may be a particular concern for such families.

Region does not appear to be an important factor in the purchase of energy-saving technologies. Of the eight variables associated with US Census Districts, only two were statistically significant in the WEATHERIZATION regression. These are the New England and the East North Central Districts, both of which are associated with an approximately 6% increase in the likelihood of investing in weatherization improvements. This is not particularly surprising, as these two districts (along with the base district, the West North Central) have consistently been among the coldest in the US as measured by the number of

HDDs. In addition, households in the Pacific District were approximately 4% more likely to invest in energy-efficient appliances. This may reflect cultural attitudes, which are generally perceived to be more liberal and environmentally conscious on the West Coast. Alternatively, it may reflect the success of local incentive programs in California and neighboring states.

Of greatest interest to this study are the variables related to property rental status and incentive programs. The PA problem is evident in these results, as owner-occupied properties were statistically more likely to invest in both kinds of energy-saving technologies. What's more, the assumption (following from Phillips' (2012) survey results) that the PA problem should be most evident in regards to weatherization improvements is borne out, as owner-occupiers are nearly 19% more likely to invest in the WEATHERIZATION regression but only 8% more likely to invest in APPLIANCES. Assuming that tenants are typically unaware of the quality of their home insulation, as Phillips suggests, it seems reasonable to assume that landlords expect to collect a higher rent premium for investing in conspicuous upgrades such as new refrigerators and dishwashers than for purchasing nearly invisible improvements to doors, windows and ceilings.

Policymakers should be largely encouraged by the results concerning incentive programs. Households are 19% more likely to invest in weatherization improvements when they receive a tax credit and 24% more likely when they receive a weatherization grant. Rebate programs focused on energy-efficient appliances performed somewhat less impressively, with households 11% more likely to invest in such improvements when the rebate is provided by the manufacturer and 13% more likely when the rebate comes from their utility provider. Less encouraging are the results associated with subsidized loans, which were not statistically significant in either regression. This is almost certainly because participation in these programs is very low, representing only 0.3% of the sample population.

CONCLUSION

The model presented above offers important insight into the nature of the PA problem in residential housing, namely that this problem is especially pronounced in regards to improvements in property weatherization. This indicates a need for policymakers to direct incentive programs towards improving insulation in rental properties.

An important shortcoming of this model is that it does not distinguish between different types of energy-saving investments within the two broad categories it considered. For instance, a household that installed either weather stripping or new windows is categorized as having made a weatherization improvement alongside households that made *both* of these investments (and perhaps also installed additional ceiling insulation, replaced doors, etc.). One way to capture these effects may be to use a count model rather than one involving a dichotomous dependent variable, but even this approach would have significant shortcomings. For instance, the energy-savings associated with weather stripping and replacing windows are not equal. Unfortunately, calculating such savings requires far more information (what was the quality of insulation both before and after the investment? What was the square footage of windows replaced, or ceiling/wall insulation improved? etc.) than is available from RECS. New data would have to be acquired, potentially at significant expense.

Policymakers concerned with addressing the PA problem may want to focus on developing grants that specifically target either landlords or tenants for the purpose of improving the weatherization of their properties. The results above indicate that such programs would be using the most effective means to address one of the most important elements of the efficiency gap.

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