Energy Savings from Weatherizing Manufactured Homes

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ABSTRACT

This study provides evidence from a randomized control trial about electricity savings from weatherizing manufactured homes as well as insights about how utilities can effectively deliver programs to manufactured home customers. In 2015 and 2016, PPL Electric Utilities (PPL Electric), a large electric distribution company in eastern and central Pennsylvania, offered Wise Homes, a weatherization program for manufactured home customers. Qualified low-income customers could receive home weatherization measures such as air sealing and duct sealing for no cost. The Wise Homes Program saved about 11% of electricity consumption between January and July 2016. Moreover, the program proved cost-effective.

Weatherization programs can help utilities serve hard-to-reach low-income customers. However, significant barriers remain to reaching the low-income customers in manufactured homes. Many manufactured home customers refused a free home weatherization despite receiving education about its benefits, suggesting that there are significant non-pecuniary costs of participation or customers lack understanding of weatherization's benefits. Better understanding these barriers should be an area of future research.

Introduction

Approximately 6% of U.S. housing units are manufactured or mobile homes (U.S. Census, 2015).[1] Manufactured homes are built on a chassis in a factory and then transported to a site. Many such homes are not energy efficient, with old ventilation systems, leaky ducting, and poorly insulated floors, walls, and ceilings. A recent study by the American Council for an Energy-Efficient Economy concluded that there is the potential to save 20% of electricity consumption and 33% of gas consumption in existing manufactured homes through adoption of cost-effective energy efficiency measures (Judkoff, Hancock, and Franconi 1990, Talbot 2012). As utility customers in manufactured homes tend to have lower incomes and spend a disproportionate share of income on energy, they may benefit significantly from investments in energy efficiency.

However, manufactured home customers face barriers to making energy efficiency improvements. These barriers may include imperfect information, split incentives, and imperfect capital markets.[2] While these barriers affect all utility customers to some degree, they may be higher for customers in manufactured homes for several reasons. First, manufactured home customers are more likely to be low-income. Twenty-five percent have incomes below the poverty level[3] and therefore few

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[1]American Housing Survey, 2015. U.S. Census Bureau. Units by Structure. Available at https://www.census.gov/programs-surveys/ahs.html.

2 Theory underlying these barriers is well developed, but there is disagreement about how substantial these barriers are (Allcott and Greenstone, 2012). Imperfect information refers to households having insufficient information about the potential benefits and costs of efficiency improvements. See Allcott (2013) and Allcott and Taubinsky (2015) for evidence about impacts of providing households with information about the benefits and costs of energy efficiency improvements. Split incentives refer to the differing incentives for owner-occupiers and renters to consume energy and make efficiency investments. See Gillingham, Harding, and Rapson (2011). Finally, energy-efficiency improvements may be cost-effective, but households may be unable to obtain loans to finance the improvements.

[3]American Housing Survey, 2015. U.S. Census Bureau. Poverty Level. Available at https://www.census.gov/programs-surveys/ahs.html.

financial resources with which to invest in energy efficiency. Second, as many manufactured home customers own their homes but not the real estate where the home is sited, they may be unable to obtain loans on terms that would allow them to undertake energy efficiency improvements. Third, manufactured home customers tend to be less educated. Approximately 15% have received a two- or four-year college degree in comparison to 43% of customers in single-family homes built on site (RECS, 2009). Less educated customers may not be as aware as other utility customers about energy efficiency. As result of these barriers, many manufactured home customers who would benefit from home weatherization may be unable to undertake such improvements.

Several utilities or energy efficiency program administrators have offered manufactured home weatherization programs to address these barriers.[4] However, the programs face several obstacles to achieving cost-effective energy savings. First, as manufactured home customers tend to be less educated, it can be harder to inform them about the program benefits and enroll them in the program. Anecdotal evidence suggests that utilities may spend more per customer to acquire a manufactured home customer than a site-built home customer. In addition, some costs of home weatherization are essentially fixed and do not vary with the size of the home or the expected savings; as such manufactured homes, which tend to be smaller, tend to be less cost-effective to weatherize than site-built homes.

This paper estimates the energy savings and cost-effectiveness of a manufactured home weatherization program of PPL Electric Utilities ("PPL Electric"), a large electric distribution company that serves customers in eastern and central Pennsylvania. In late 2015 and early 2016, PPL Electric weatherized the manufactured homes of eligible low-income customers at no charge. The weatherization included such measures as duct repair and air sealing as well as wrapping exposed pipes, installing weather stripping, and caulking wall, floor, and ceiling cracks. The program also provided customers with LEDs, advanced power strips, and aerators and showerheads in homes with electric water heaters.

A significant feature of the program was that it was implemented as a recruit-and-delay randomized field experiment. Manufactured home customers who indicated interest in receiving a home weatherization were randomly assigned to a group that would receive a weatherization in 2015 or 2016 (treatment group) or to a control group that would receive a weatherization in 2017 (control group). To estimate energy savings, we collected monthly customer bills and compared the energy consumption of customers in the randomized treatment and control groups, controlling for differences between customers in pre-treatment consumption. Because assignment to receive a home weatherization was uncorrelated with customer and home characteristics affecting energy consumption, comparison of the consumption of treatment group and control group customers is expected to produce an unbiased estimate of savings.

On average, weatherization saved about 3 kWh per day per manufactured home or 11% of electricity consumption between December 2016 and July 2017.[5] Savings were estimated conditional on customer fixed effects, month-by-year fixed effects, and weather. The estimated savings were robust to different specifications and estimation methods. Also, based on a comparison of thermostat set points reported by customers before and after weatherization, it does not appear that manufactured home customers increased their demand for space conditioning after weatherization.

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4 Puget Sound Energy, PPL Electric Utilities, Progress Energy Florida, and Wisconsin Energy Conservation Corporation offer home weatherization programs for manufactured home customers.

5 PPL Electric reported energy savings from the manufactured homes weatherization program in an Annual Report to the Pennsylvania Public Utilities Commission (Cadmus Group, 2016). The results in this paper differ from those reported in the annual report for two reasons. First, this paper's analysis is limited to the manufactured homes included in the randomized field experiment. PPL Electric weatherized 30 homes that were not randomly assigned to receive treatment. Second, this paper reports savings estimated through the end of July 2016. PPL's report to the Commission estimated savings between December 2015 and May 2016. Nevertheless, the savings and cost-effectiveness estimates and conclusions of this paper are very similar to those reported by PPL Electric.

Although many low-income home weatherization programs are not cost-effective for utilities, PPL Electric's program proved cost-effective for a range of discount rates. Two principal factors contributed to the program's cost-effectiveness. First, the program targeted manufactured home parks, allowing PPL Electric to market and weatherize multiple homes in the same park and thereby save on marketing, transportation, and contractor labor costs. Second, the program focused on high-impact but low-cost energy efficiency measures such as duct repair and air sealing. The program did not attempt to undertake more labor- and materials-intensive measures such as adding insulation to exterior walls and ceilings.

An interesting finding was that despite the utility's offer to weatherize manufactured homes for free, the program had difficulty attracting participants. Recruiting took much longer and was less successful than expected. Moreover, only 40% of customers who signed up for the program went forward with a home weatherization. This suggests that there may be significant non-pecuniary costs to participating in a home weatherization program related to the inconvenience of scheduling with a home contractor, having a household member present for the weatherization, or simply having a contractor inside the home.

Manufactured Homes and PPL Electric's Wise Homes Program

Americans inhabit about 6.9 million manufactured homes (American Housing Survey 2013). Manufactured homes are factory-assembled, built on a chassis, and transported to the site where they will be occupied. Figure 1 shows a typical manufactured home.

Figure 1. Manufactured Home

In site-built homes, most heat loss occurs through conduction—energy that passes through the walls, windows, doors and ceiling. Manufactured homes lose heat through not just conduction but also through infiltration of cold air through cracks and gaps in walls and ceilings. Furthermore, leaky ducts can cause significant energy losses even before space heat is delivered to the home interior.

Despite constituting 6% of housing units and accounting for 3.5% of residential space heating energy consumption nationally (RECS, 2009), the United States spends relatively little on energy efficiency of manufactured homes. Currently, there are not any national energy standards for the manufacture of mobile homes. However, the U.S. Department of Housing, which regulates the manufacture of mobile homes for protection of human health and safety, requires that such homes have heat loss from walls, ceilings, floors, windows, and external ducts below a maximum level.[6] HUD last updated the code in 1994.

Also, occupants of manufactured homes tend to be poorer and not have financial resources to invest in home weatherization despite the potential for positive returns from such investments. Table 1 compares the demographic and housing characteristics of households in manufactured homes and single-family homes.

Table 1. Manufactured home customer characteristics

	Manufactured Homes	Single Family Homes
Household head age (Years)	50.7	52.3
Household head education: associate degree or higher (%)	14.6	42.9
Household income less than $30,000 (%)	60.3	23.9
Renter (%)	17.8	10.8
Floor space (sq. ft)	985.3	2056.7
Year built	1985.4	1971.0
Heating fuel (%)		
Electricity	56	28
Gas	20	54
Propane	12	6
Other	12	12

Source: RECS (2009) Microsample. All values are sample weighted means or frequencies.

Not only do manufactured home customers tend to have lower incomes, many do not own the land where their home is sited and therefore cannot obtain traditional mortgage or home equity loans to undertake energy efficiency improvements.

Furthermore, manufactured home occupants tend to be less educated and therefore may have less knowledge about the potential benefits of investing in energy efficiency. Only 15% of manufactured home household heads attained an associate's degree or higher. Finally, manufactured home occupants are more likely to be renters, who have weaker incentives to invest in energy efficiency (Gillingham, Harding, and Rapson, 2011).

Since a significant share of residential utility customers occupy inefficient manufactured homes and because of impediments many of these customers face undertaking efficiency improvements, utilities and energy efficiency program administrators have begun to direct resources to these customers. A handful of utilities in Kansas, Kentucky, Michigan, Oregon, Pennsylvania, and Wisconsin now operate manufactured home weatherization programs.[7] However, utilities confront a number of factors that negatively affect the cost-effectiveness of home weatherization programs including high costs of enrolling customers, the relatively short expected life of most manufactured homes, and fixed costs of home weatherization that make weatherizing smaller homes less cost-effective.

6. Department of Energy is currently undertaking a rulemaking to set energy efficiency standards for manufactured homes. The proposed federal rule is based on the most recent version of the International Energy Conservation Code for manufactured housing. See https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=64#current_standards

7 See U.S. Department of Energy Better Buildings Residential Network Peer Exchange webinar on manufactured homes, December 8, 2016.

PPL Electric's Wise Home Program

In 2015 and 2016, PPL Electric offered Wise Homes, a weatherization program for manufactured home customers. Qualified low-income customers could receive home weatherization measures such as air sealing and duct sealing for no cost.[8] By offering manufactured home weatherization for free, the Wise Homes Program sought to reach low-income customers who tended to have below-average rates of energy efficiency program participation.[9]

PPL Electric implemented the pilot as a "recruit-and-delay" randomized control trial (RCT). This involved recruiting customers to the pilot study and then randomly assigning some customers to receive a weatherization as soon as possible and other customers to receive weatherization with a delay of one year or more. The delayed group would constitute a randomized control group and provide the consumption baseline for weatherized homes. The pilot was implemented as an RCT to control for self-selection of program participants and to obtain an unbiased estimate of savings.

The RCT was implemented in several steps. First, using satellite imagery, GIS computer mapping software, and utility customer billing data, PPL Electric identified large mobile home parks in the utility's service area. PPL Electric targeted parks in the eastern half of its service area, and each park comprised a minimum of 30 manufactured homes.

PPL Electric targeted customers in large parks to minimize program implementation costs and to maximize the program's cost-effectiveness. By weatherizing multiple homes in the same park, the program could save on marketing, transportation, and labor costs.

Next, beginning in August 2015, the utility and its program implementation contractor recruited customers by sending promotional materials and utility representatives to targeted parks. The utility expected manufactured home customers to receive the free weatherization program enthusiastically, but the program had trouble recruiting. Recruitment took longer than expected, and PPL Electric ultimately weatherized fewer homes than targeted. Interviews with the program implementation contractor suggested that many manufactured home customers did not trust the offer of a free weatherization from the utility or did not understand the potential benefits (Cadmus, 2016). In addition, there may have been non-pecuniary costs of participating related to scheduling and being present for the weatherization. As Figure *2* shows, between August 2015 and February 2016, the utility recruited 390 customers to the pilot and weatherized 110 manufactured homes by February 2016, well short of the original goal of weatherizing 400 homes.

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[8] Customers had to meet the following eligibility requirements to participate:

- Received electricity service from PPL Electric Utilities
- Lived in the manufactured home at the existing locations for at least 12 months
- Owned the home or had obtained written permission from the owner to weatherize the home
- Resided in permanently established manufactured home (i.e., not wheeled, like a recreational vehicle [RV]).

9Customers who had previously obtained weatherization services through PPL Electric's other low-income energy efficiency programs (Universal Services Program (USP) or Act 129 WRAP or had received an E-Power Wise Program energy conservation kit) were eligible to participate. The potential for additional savings from these homes would be less.

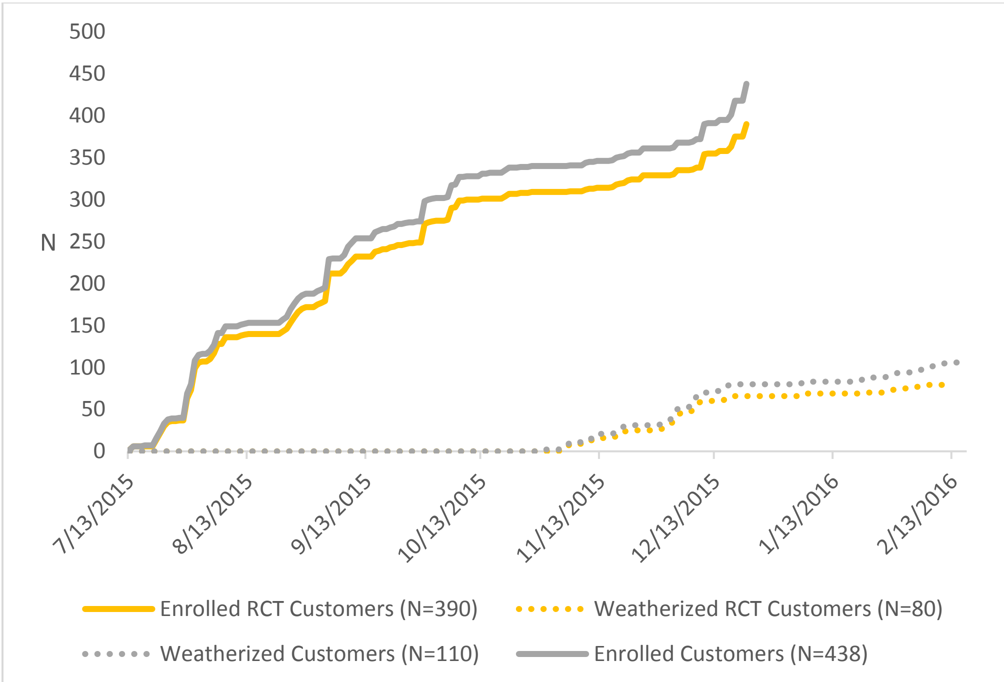

Figure 2. Enrolled manufactured home customers and weatherized homes

When a customer signed up for the program, the customer was asked whether the manufactured home used electricity for space heating, the type of electric heating system (forced air furnace, heat pump, or baseboard electric resistance heater), and whether the home was air conditioned using a central system or window units. Customers were then classified by heating equipment type (electric forced air furnace, baseboard electric heat, or other) and whether they had air conditioning (either central system or window units).

This paper focuses the analysis on two customer types. Most eligible customers who enrolled in Wise Homes had either an electric forced-air furnace and air conditioning or a non-electric heating system and air conditioning. PPL Electric randomly assigned these customers to either a treatment group or control group.[9] Treatment group customers were scheduled to receive home weatherization in late 2015 or early 2016, while customers in the control group were told that their homes would be weatherized in spring 2017.

Table 2 shows the numbers of customers of each home type assigned to the treatment and control groups.

[9] All eligible manufactured home customers who had baseboard electric heat or who did not have air conditioning received a home weatherization. These customers did not participate in the recruit-and-delay RCT, and their savings are not estimated in this paper.

Table 2. Random assignment of customers to treatment and control groups by home type

Sample Sizes	Treatment Group	Treatment Group & Weatherized	Control Group
Electric Heat & AC	45	31	45
Non-electric heat & AC	150	49	150
Total	**195**	**80**	**195**

Notes: All numbers are counts of customers by home type in the manufactured homes RCT.

However, as Table 2 shows, only 80 of 195 homes (41%) assigned to the treatment group received weatherization. For many treatment group customers, there was a delay of several months between when the customer opted in to the pilot and when their home was weatherized because of slow pace of the recruitment. This delay may have contributed to a significant percentage of treatment group customers who subsequently declined to move ahead with weatherizing their homes.

The pilot focused on reducing electricity consumption for space conditioning through air sealing and repairing ducts. Program technicians inspected and repaired ducts below and above the ground floor of homes with electric forced air furnaces (and air conditioning) and ducts above ground of homes with other kinds of space heating system. In addition, technicians installed weather stripping, window insulation, outlet gaskets, pipe insulation, and window air conditioner covers at no cost. Technicians also installed LEDs, advanced power strips, and aerators and showerheads in homes with electric water heaters. The program did not address substandard ceiling or exterior wall insulation levels.

Estimation Approach

To estimate energy savings from weatherizing manufactured homes, we compared the electricity consumption of customers in treated and untreated homes, using the random assignment of customers to the treatment group as an instrumental variable for receiving a home weatherization. Originally, the random assignment of customers to the treatment and control groups was intended to ensure that a customer's decision to weatherize was uncorrelated with his or her energy consumption. However, many customers assigned to receive a home weatherization decided not complete one, meaning that it was not possible to estimate savings from home weatherization simply by comparing the randomized treatment and control groups. Instrumental variables estimation was necessary to control for the self-selection of treatment group customers who received a weatherization.

We start by comparing pre-treatment consumption of the randomized treatment and control groups.

Table 3 shows the mean average daily consumption of customers in both groups.

Table 3. Comparison of electricity consumption randomized treatment and control groups

	N	Treatment Group (kWh)	Control Group (kWh)	Difference (kWh)
Electric Heat & AC homes	90	47.4	45.9	-1.5
		(3.3)	(3.2)	(4.6)
Non-electric heat & AC homes	300	29.8	27.5	-2.3
		(1.2)	(1.1)	(1.7)
All homes	390	33.9	31.8	-2.1
		(1.3)	(1.3)	(1.8)

Notes: Average daily electricity consumption between October 2014 and July 2015. Standard errors in parentheses. None of the differences was statistically significant at the 10% level.

On average, treatment group customers consumed about 2.1 kWh more electricity per day than control group customers between November 2014 and July 2015. However, this difference was not statistically significant. Moreover, neither of the differences for the two subgroups was statistically significant.

Also, Figure 3 shows that the distributions of pre-enrollment average daily electricity consumption of the treatment and control groups.

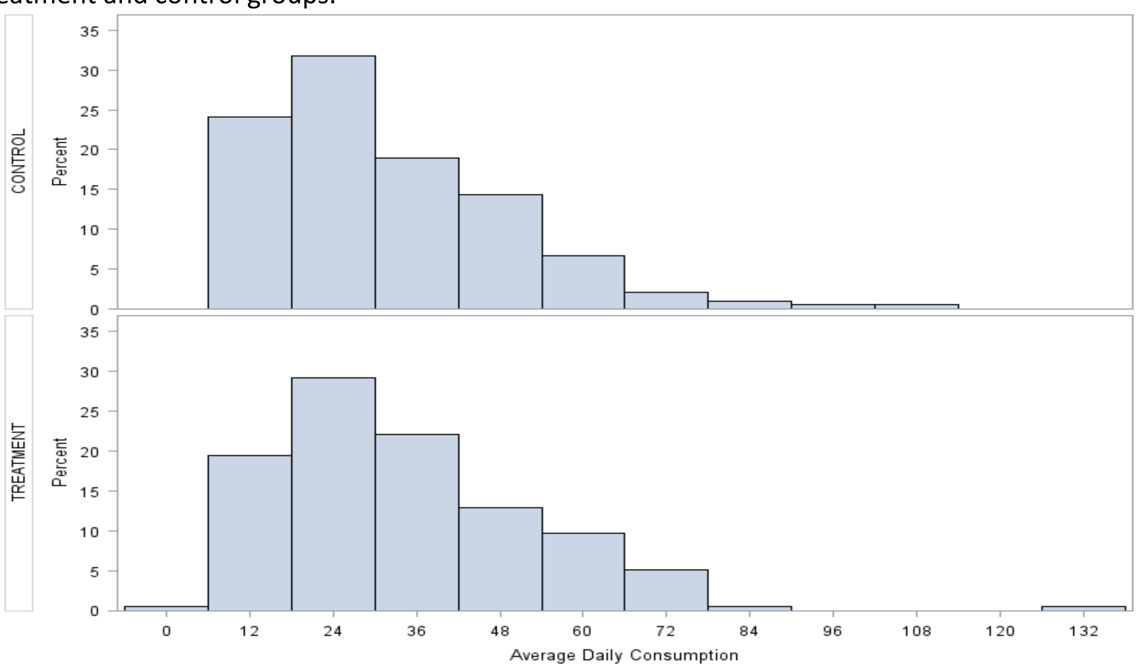

Figure 3. Distribution of pre-enrollment electricity consumption of randomized treatment and control group customers

The distributions were very similar, though there was slightly more probability mass above 80 kWh/day for customers in the control group. As described below, we control for these pre-existing differences in the savings estimation.

Estimation Equation

We estimate a difference-in-differences model, comparing energy consumption of treatment and control group customers before and after weatherization of homes was completed. We use instrumental variables, two-stage least squares (IV-2SLS) to estimate the model to account for over half of customers randomly assigned to receive a weatherization who refused one.

Suppose that electricity consumption of manufactured home customer i in month t, e_{it}, is given by:

$$e_{it} = \delta w_{it} + \beta X_{it} + \alpha_i + \tau_t + \varepsilon_{it} \qquad \text{(Equation 1)}$$

where w_{it} is an indicator for whether the customer received a home weatherization through the program in month t or in a previous month (=1 if the home received a weatherization, and =0, otherwise), X_{it} is a vector of time-varying characteristics for customer i such as weather, α_i is the customer-specific error, τ_t is a time-period specific error, and ε_{it} is idiosyncratic error for customer i in period t. We control for customer and time-period errors with, respectively, customer and month-by-year fixed effects. The main parameter of interest is δ, which indicates the average energy savings per weatherized home per month.

Estimating equation 1 by OLS would result in a biased estimate of δ because the decisions of 59% of treatment group customers to refuse to weatherize their homes may have been correlated with unobservable characteristics affecting energy consumption. In particular, the main unknown was the pre-weatherization space heating efficiency of manufactured homes. If program participants had the least efficient homes, comparison of participants to non-participants would likely produce a savings estimate that was biased downward. Similarly, if participants were most knowledgeable about energy efficiency and already had efficient homes, comparison to nonparticipants would likely produce a savings estimate that was biased upward.

To deal with the potential endogeneity of the treatment group customer participation decision, we estimate Equation 1 by instrumental variable two-stage least squares (IV-2SLS), using the assignment of homes to the treatment group as an instrumental variable for receiving a weatherization. Since assignment to the treatment group was random and only homes in the treatment group received a weatherization, assignment to the treatment group would have been uncorrelated with energy consumption but correlated with receiving weatherization, and can be used an instrument.

The first-stage decision to weatherize the home can be modeled as:

$$w_{it} = \gamma d_i * m_{it} + \lambda_i + \tau_t + \mu_{it} \qquad \text{(Equation 2)}$$

where w_{it} is defined as above, di is a variable indicating whether the customer was randomly assigned to the treatment group (=1) or to the control group (=0), and m_{it} is a variable indicating whether PPL Electric would have weatherized customer i's home in month t. This variable equaled one if the month was during or after the predicted weatherization month for home i and equaled zero otherwise. Each customer's weatherization date was predicted as a function of the customer's type, enrollment date, which was a function of recruiting and marketing schedule, and township of residence. We interact d_i, which does not vary over time, with m_{it} to account for differences between homes in the weatherization month and to increase the explanatory power of the first-stage regression. The date of home weatherization depended on PPL Electric customer recruitment and weatherization schedules and did not depend on customer characteristics, as PPL Electric attempted to weatherize multiple homes in a park simultaneously.

Savings Estimates

Table 4 shows results from the IV-2SLS estimation of Equation 1. The top panel shows results from estimation of the first-stage equation. The bottom panel shows the second-stage results, which include an estimate of the average daily electricity savings per customer who opted into the pilot and chose to weatherize his or her home.

Table 4. Instrumental variables two-stage least squares estimates

	Model 1	Model 2	Model 3	Model 4	Model 5
	Panel A: First stage (Dependent var = Received a Home Weatherization)				
Treatment Group * Eligible to Receive a Weatherization	0.411***	0.377***	0.377***	0.636***	0.313***
	(0.008)	(0.008)	(0.008)	(0.018)	(0.009)
Month-by-year fixed effects	Yes	Yes	Yes	Yes	Yes
Customer fixed effects	No	Yes	Yes	Yes	Yes
Weather variables	No	No	Yes	Yes	Yes
R^2	0.342	0.571	0.571	0.711	0.547
N customers	380	380	380	90	290
N obs	7848	7848	7848	1792	6056
	Panel B: Second stage (Dependent var = average daily consumption)				
Weatherization	2.54	-3.10**	-2.14*	0.11	-3.46**
	(1.75)	(1.45)	(1.28)	(2.22)	(1.53)
Month-by-year fixed effects	Yes	Yes	Yes	Yes	Yes
Customer fixed effects	No	Yes	Yes	Yes	Yes
Weather variables	No	No	Yes	Yes	Yes
R^2	0.108	0.663	0.737	0.759	0.678
N	7848	7848	7848	1792	6056

Notes: In first stage model, Treatment Group = 1 if customer was randomly assigned to the treatment group and = 0 otherwise. Eligible to Receive a Weatherization =1 if the time period (month) was during or after when a treatment group customer could have receive a weatherization based on PPL Electric's schedule for completing weatherization. In the second stage, weatherization = 1 if the customer's home was weatherized in a current or previous month. ***, **, * denote estimate was statistically significant at the 1%, 5%, or 10% levels.

We estimate three main specifications. Model 1 only includes month-by-year fixed effects as control variables. The first stage indicates that random assignment to the treatment group increased the probability of home weatherization by 41%, which, as expected, approximately equals the percentage of treatment group customers who weatherized their homes. The estimate of γ was highly statistically significant (t-statistic=49.7) and passes the weak instrument test (Andrews and Stock, 2006). The second stage estimate indicates no energy savings, however. The estimate of δ is positive (savings = -2.5 kWh per day per customer) and statistically insignificant.

Substantial variation between customers in electricity consumption (see Figure 3) could explain why model 1 could not detect any savings. Model 2 adds customer fixed effects to account for this source of variation. After adding customer fixed effects, the estimated electricity savings become positive and statistically significant at the 5% level. On average, home weatherization reduced daily electricity consumption by 3.1 kWh or 11.3% of baseline customer consumption.

Model 3 adds two weather variables as independent variables: cooling degree days (CDD) and an interaction variable between heating degree days (HDD) and an indicator for whether the manufactured home was heated with electricity. In comparison to model 2, the estimated daily electricity savings per weatherized home decrease to about 2.1 kWh or 7.8% but remained statistically significant.

Model 4 was only estimated with data for 90 manufactured homes with electric space heating. The savings estimate was small and statistically insignificant. Model 5 was estimated only with data for 290 manufactured homes with non-electric space heating. Home weatherization saved an average of 3.5 kWh per non-electric heat home per day or 12.6% of consumption.

Robustness

The IV-2SLS estimates indicate savings of between 8% and 11% of electricity consumption. As a check on the IV-2SLS estimates, we estimated savings in reduced form by comparing the consumption of the randomized treatment and control groups before and after weatherization. Specifically, we estimated:

$$e_{it} = \theta d_{it} * m_{it} + \beta X_{it} + \alpha_i + \tau_t + \varepsilon_{it} \quad \text{(Equation 3)}$$

where all variables are defined as above and X includes monthly CDD and HDD for customer i during month t. The coefficient theta represents the average daily savings per treatment group customer, which is an average across customers in the treatment group who received a home weatherization and those who did not. To obtain an estimate of weatherization savings, we then scaled the resulting differences-in-differences estimate by the percentage of customer-months during the treatment period for which treatment group homes were weatherized. This percentage equaled 41.9%.

Estimation of equation 3 produced an estimate of -1.2 kWh per day per treatment group customer (est. s.e.=0.68).[10] Scaling this estimate by the percentage of treatment group customer-months with home weatherization yields an estimate of average daily savings per weatherized home of 2.8 kWh or 10%, which is statistically indistinguishable from the IV-2SLS estimate from model 3.

Why Weren't Electricity Savings Larger?

On average, PPL Electric's manufactured home weatherization program saved 10%, a substantial percentage of electricity consumption. However, engineering analyses suggest that electricity savings from HVAC shell and equipment measures can equal 20% (Talbot, 2012). Why did savings from PPL Electric's manufactured home weatherization program fall short of this level?

First, PPL Electric's program only focused on two of three high impact weatherization measures for manufactured homes: air sealing and duct repair. The savings analysis suggests that these measures can produce significant energy savings. However, the program did not seek to improve efficiency by adding insulation to exterior walls or attic ceilings. It is likely that weatherized manufactured homes continued to lose significant amounts of space heat through conductive heat loss and could have saved additional energy by adding insulation to the attic ceiling. Similarly, many weatherized homes may have had inefficient furnaces or air conditioners. Adopting these measures could have produced savings exceeding 20% of consumption, though adding these measures may not have proved cost-effective.

Another possible explanation for why the program did not save more energy is that households increased their demand for space conditioning after receiving a home weatherization. Economic theory predicts that duct repair and air sealing would have reduced the household's cost of space heating and cooling, causing households to increase the number of heating hours or the home's interior temperature, an effect known as "rebound" or "take-back". However, surveys about thermostat setting behavior suggests households did not increase their demand for space heating or cooling. We collected data on household thermostat set points before weatherization and after weatherization for weatherized

[10] When weather variables were excluded, the estimate of average daily savings per weatherized home was 2.78 kWh.

homes.[11] Table 5 shows results of OLS regressions of thermostat set points for customers receiving a home weatherization.

Table 5. Impact of weatherization on household demand for space heating and space cooling

	Space Heating	Space Cooling
Thermostat set point before weatherization	69.8	72.2
Δ T-stat set point after weatherization	-2.30***	-1.57
	(0.80)	(1.70)
R^2	0.063	0.007
N	125	129

Notes: Δ T-stat set point was estimated with an OLS regression of customer thermostat set point on constant and post-weatherization indicator variable. Standard errors in parentheses. *** denotes estimate is statistically significant at the 1% level. Customers were surveyed at enrollment and in summer 2016, approximately six to eight months after receiving a home weatherization. Analysis sample only includes responses from customers receiving home weatherization. It was not possible to link individual respondents across surveys.

During winter, households receiving home weatherization reduced their thermostat set points by an average of 2.3°F. This impact was statistically significant and opposite of what was predicted. It may suggest that before weatherization, customers could not maintain the temperature of their homes at the thermostat set point. However, after weatherization, households could reduce the thermostat set point and maintain the same or a higher interior temperature. In post-treatment surveys, many participants reported experiencing an increase in thermal comfort. During summer households reduced the thermostat set point by about 1.7°F, but the effect was not statistically significant.

This comparison of thermostat set points before and after home weatherization has several significant limitations. First, some participants responded to both pre- and post-weatherization surveys, but it was not possible to link individual participants between surveys. As a result, the analysis assumes the responses are independent and estimates the standard errors by OLS without clustering on individual customers. Second, it is likely that some participants responded to the pre-survey but not the post-survey, and vice-versa, so the composition of the survey sample may have changed over time. Finally, the results do not incorporate a randomized control group, so it is not possible to rule out, though it is unlikely, that some or all changes in thermostat set points were attributable to non-programmatic factors.

Cost-Effectiveness of Weatherizing Manufactured Homes

Pennsylvania Act 129 requires electric-distribution companies (EDCs) with over 100,000 customers to pursue cost-effective energy efficiency. Furthermore, the Act requires large EDCs to offer energy efficiency programs for low-income customers. Was the weatherization of low-income manufactured homes cost-effective for PPL Electric?[12]

We collected information about PPL Electric's Wise Home Program administration and implementation costs, the utility's avoided energy and capacity costs, which determine the utility's benefits, and other data such as line-loss factor and average measure life needed to estimate the

[11] Household self-reports of thermostat set points were obtained from mail-in surveys at enrollment and from web surveys approximately five to six months after PPL Electric completed the last weatherization.

[12] Independent evaluation found that PPL Electric's Wise Home Program was cost-effective in Pennsylvania Act 129 Program Year 7 with a benefit-cost ratio of 1.18.

program's cost-effectiveness. We then evaluated the program cost-effectiveness by comparing the net present value of program benefits and costs using different assumptions about the utility's discount rate.

Table 6 shows the inputs for the cost-effectiveness calculation. This cost-effectiveness analysis was limited to the homes included in the RCT, and the costs includes all fixed costs that did not vary with the number of weatherized homes.

Table 6. Cost-effectiveness calculation assumptions

Number of weatherized homes	Utility's Average Cost per Weatherized Home	Average Annual Energy Savings per Weatherized Home (kWh/yr)	Line Loss Factor	Measure Life (years)	Annual Cost Escalator
80	$923.87	956.3	0.083	13.2	3%

Notes: See appendix for sources of assumptions. Average cost includes utility program fixed costs and costs that vary with the number of homes weatherized. Annual energy savings are measured at the home.

Table 7 shows estimates of program cost effectiveness for different utility discount rates.

Table 7. Cost-effectiveness of manufactured home weatherization program

Utility Discount Rate	NPV of Program Benefits	NPV of Program Costs	Benefit-Cost Ratio
4%	$92,371	$73,909	1.25
6%	$82,665	$73,909	1.12
8%	$74,510	$73,909	1.01
10%	$67,614	$73,909	0.91

Notes: See appendix for details about calculation of discounted program benefits and costs.

At discount rates less than or equal to 8%, a manufactured home program of this size and design would prove cost-effective. At a discount rate of 8%, the benefit-cost ratio was 1.01, with an NPV of program benefits of $74,510. At lower utility discount rates, the program would prove more cost-effective. As this calculation only considers utility program costs and benefits such as avoided energy and capacity costs, it does not include societal benefits such as reductions in harmful emissions such as NOx, SOX, and greenhouse gases or increases in comfort or improvements in health of occupants of weatherized manufactured homes or participant non-pecuniary costs related to the inconvenience of scheduling and being present for the weatherization. It is not clear whether accounting for these benefits and costs, which are difficult to quantify, and measuring the program cost-effectiveness from a societal perspective would make the program appear more or less cost-effective.

Many other home weatherization programs across the United States have not proved cost-effective (Fowlie, Greenstone, and Wolfram 2015; Allcott and Greenstone, 2017). It is likely that despite difficulties in recruiting customers PPL Electric's program was cost-effective for two reasons. First, the program targeted manufactured home parks, allowing program administrators and implementers to market and weatherize multiple homes in the same park and thereby save on marketing, transportation, and contractor labor costs. Second, the program installed low-cost energy efficiency measures. The program focused on duct repair and air sealing, which have high energy savings impacts but low materials and labor costs. The program did not attempt to undertake more labor- and materials-intensive measures such as installing insulation.

Conclusions

This study provides evidence from a RCT about energy savings from weatherizing manufactured homes as well as insights about how utilities can effectively deliver programs to manufactured home customers.

This study demonstrates that manufactured home weatherization programs can save significant energy. PPL Electric's Wise Homes Program saved about 11% of electricity consumption between January and June 2016. Moreover, the program proved cost-effective for a range of discount rates.

Weatherization programs can help utilities to serve hard-to-reach low-income customers such as those in manufactured homes. However, significant barriers remain to reaching these customers. Many manufactured home customers refused a free home weatherization despite receiving education about its benefits, suggesting that there are significant non-pecuniary costs of participation or customers lack understanding of weatherization's benefits. Better understanding of these barriers should be an area of future research.

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