DYNAMICS EFFECTS OF UTILITY ENERGY CONSERVATION PROGRAMS: A RESIDENTIAL RETROFIT PROGRAM EXAMPLE

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ABSTRACT

The Bonneville Power Administration (BPA) operated a Residential Weatherization Pilot Program from 1980 through 1982. The program provided free home energy audits to 7200 electrically heated homes in the Pacific Northwest and gave zero-interest loans to weatherize 4100 of these homes. The total cost of the program was almost $11 million.

This paper estimates the energy-saving effects of the BPA program. The data used include one year of preprogram and three years of postprogram electricity consumption records. The total annual electricity saving experienced by the households that received both an energy audit and a weatherization loan averaged 5300 kWh/year one year after participation, increasing to 6000 kWh and 6500 kWh two and three years after participation. The net annual electricity saving that can be directly attributed to the BPA pilot program for these households averaged 4500 kWh (15% of preprogram use) one year after participation and declined to 4300 kWh two years and 4200 kWh three years after participation.

INTRODUCTION

A major concern in assessing the worth of conservation programs is the durability of the energy savings. Consider, for example, a utility that encourages its customers to replace wornout room air conditioners with high-efficiency units, to cut summer peak loads. To determine program benefits, the utility needs information on the energy savings and peak load reductions due to high-efficiency units throughout the lifetime of these air conditioners. In principle, this involves collection of energy use and load data for several years.

Unfortunately, because most utility and government conservation programs are recent, little information is available concerning their long-term energy savings. The purpose of this paper is to present results obtained in a recent evaluation of one program - the BPA Residential Weatherization Pilot Program (BPA, 1980). This analysis yields information on the energy-saving effects of the program one, two, and three years after participation. This is, as far as we know, the first study to closely examine actual (measured) energy savings due to a conservation program over such a long time span. [Kushler and Witte (1984) analyzed energy savings due to the Michigan RCS program two years after participation. Hirst and Goeltz (1985) conducted a similar analysis of the Minnesota RCS program.]

The program ran from Spring 1980 through 1982. It was funded by BPA and administered by 11 small, public power utilities in Washington, Oregon, Idaho, and Western Montana. Roughly two-thirds of the 60,000 residential customers served by these 11 utilities were eligible for participation: single-family homes that used electricity for space heating.

The program offered free home energy audits, to identify cost-effective conservation measures to reduce space heating and water heating electricity use. The program also included zero-interest, deferred-payment loans for electrically-heated single-family homes; the loans paid for installation of measures recommended during the audit. During its lifetime, 7200 homes were audited and 4100 loans (averaging $2200) were made. The total cost of the program (including audits, loans, postinstallation inspections and administration) was $11 million (Hirst et al., 1983).

The most important purpose of the evaluation was to develop accurate and credible estimates of the electricity savings that could be directly attributed to the pilot program. In developing such estimates, it is important to identify and separate the various factors that influence electricity consumption such as ambient temperatures, electricity prices, and changes in household composition, as well as participation in the BPA program. Because accurate attribution of changes in energy consumption to each of these factors is difficult, we developed and implemented a variety of approaches to estimate the energy-saving effects of the pilot program (Hirst et al., 1983, 1984, and 1985).

The analyses yield estimates of the total and net savings due to BPA's pilot program. Total saving refers to the reduction in annual electricity use experienced by the audit + loan households (weatherized as part of the program). Net saving refers to the incremental annual electricity saving, the saving that can be directly attributed to the pilot program. The net saving is the difference between the total saving and the saving that these weatherized homes would have achieved on their own had there been no BPA program. Information from the nonparticipants is used to infer the no-program energy savings for participants. This definition of net saving ignores the possibility that the program stimulated some retrofit activity and electricity savings among nonparticipants (through what might be called information contagion).

This evaluation is particularly interesting in two respects. First, analysis of program energy savings was based primarily on utility records (actual household electricity bills), rather than on household self-reports of actions taken. Second, the analysis included three years of postprogram data, which allows examination of the temporal effects of this program. Details of the evaluation, including the data available and the analytical methods used, are in the report by Hirst, White, and Goeltz (1985).

ENERGY ANALYSIS: SCOREKEEPING RESULTS

We began our analysis of electricity consumption using the Princeton Scorekeeping Model (PRISM) developed by Fels (1984). PRISM computes, for each household-year of electricity billing data, weather-adjusted electricity use (normalized annual consumption, NAC) as well as reference temperature, baseload consumption, and space heating consumption (Table 1). The mean value of R^2 across the 349 household models is 0.79; 70% of the models have an R^2 of 0.5 or better. The heating slope and baseload coefficients are generally quite statistically significant.

Table 1. Summary (Means) of Normalized Annual Consumption Models for Each Household

	Audit + loan	Audit only	Nonparticipants
Electricity use (kWh/year)			
Total NAC[a]			
year 1	29,350	24,950	25,410
year 2	23,940	21,760	23,840
year 3	22,820	19,710	22,670
year 4	22,420	20,010	21,890
Heating[b]			
year 1	15,960	14,110	13,770
year 2	9,560	7,890	10,220
year 3	9,010	6,530	9,370
year 4	9,070	7,270	9,050
Reference temperature (°F)			
year 1	60	59	59
year 2	56	58	56
year 3	57	55	56
year 4	57	56	57
Total saving (kWh/year)[c]			
year 1 - 2	5,410(17)	3,190(11)	1,570(5)
year 1 - 3	6,530(21)	5,240(20)	2,740(9)
year 1 - 4	6,930(22)	4,940(20)	3,520(12)
Model R^2	0.80	0.74	0.80
No. of households	179	38	132

[a]Normalized annual consumption (NAC) is the sum of the baseload and heating components. The heating component is computed on the basis of the long-run value of heating degree days (average of 5800 at 65°F base) at the best reference temperature for each household.

[b]Weather sensitive electricity use. Baseload (nonweather sensitive) use is the difference between total and heating use.

[c]The numbers in parentheses are the percentage savings, i.e., $100*(NAC_1 - NAC_i)/NAC_1$.

Preprogram (1980/81) electricity use is about 10% higher, on average, for the AL households than for the AO and NP households. See Hirst et al. (1983) for a discussion of other differences among the three groups. Roughly speaking, total electricity use is split equally between heating and baseload purposes for all three groups. Similarly, reference temperatures average just under 60°F across all three groups.

These averages hide considerable variation in NAC among these households. For example, the standard deviation is about 10,000 kWh/year, roughly 40% of the mean value.

The reduction in NAC from year 1 to year 2 is greatest for AL households, averaging 5400 kWh/year compared with 3200 for AO households and 1600 for NP households. However, the reduction in electricity use between years 2 and 3 is greatest for AO households, averaging 2100 kWh/year, compared with 1100 kWh for AL and 1200 kWh for NP households. The reductions between years 3 and 4 are small for the AL and NP households and slightly negative for the AO households. The overall effect is an average four-year reduction of 6900 kWh/year (24% of preprogram use) for the AL households, 4900 kWh (20%) for the AO households, and 3500 kWh (14%) for the NP households. Given the small size of the AO sample, their results must be viewed with caution.

The electricity savings are directly related to preprogram consumption for all three groups of households (Figures 1 - 3). This strong positive relationship between energy savings and preprogram energy use was also found in our evaluation of home energy audit and retrofit loan programs in Minnesota (Hirst and Goeltz, 1985).

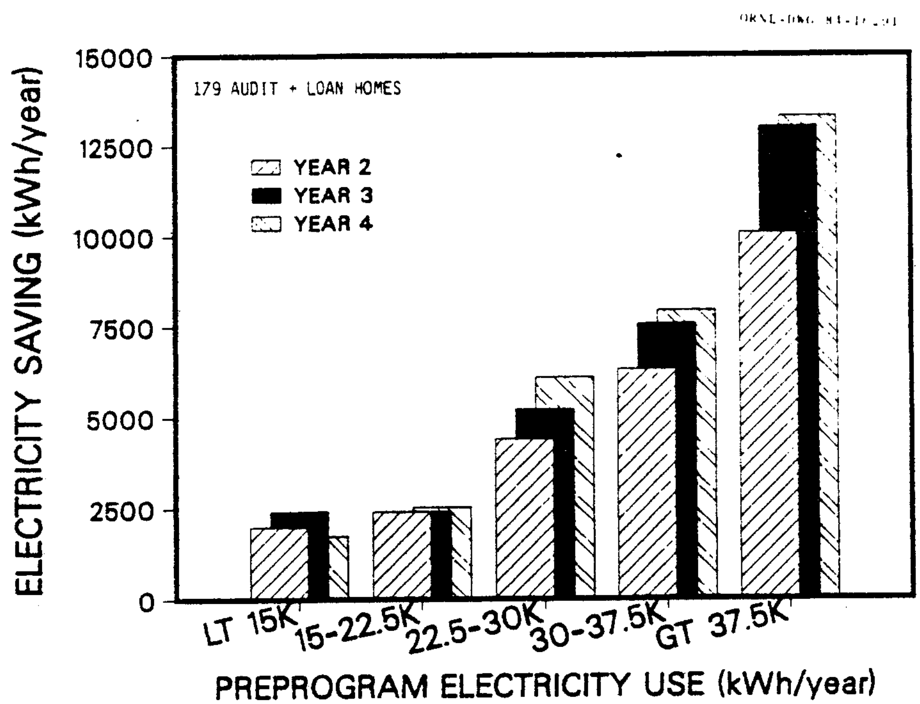

Figure 1. Reductions in Annual Electricity Use in Years 2, 3, and 4 (Relative to Year 1) as a Function of Preprogram Electricity Use (NAC_1) for Audit + Loan Households.

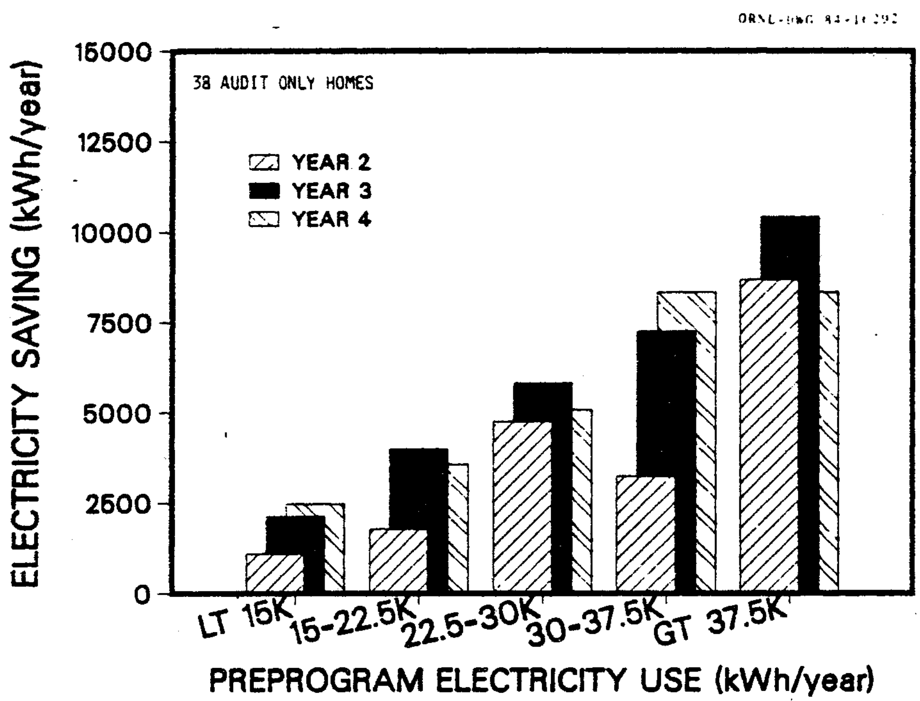

Figure 2. Reductions in Annual Electricity Use in Years 2, 3, and 4 (Relative to Year 1) as a Function of Preprogram Electricity Use (NAC_1) for Audit Only Households.

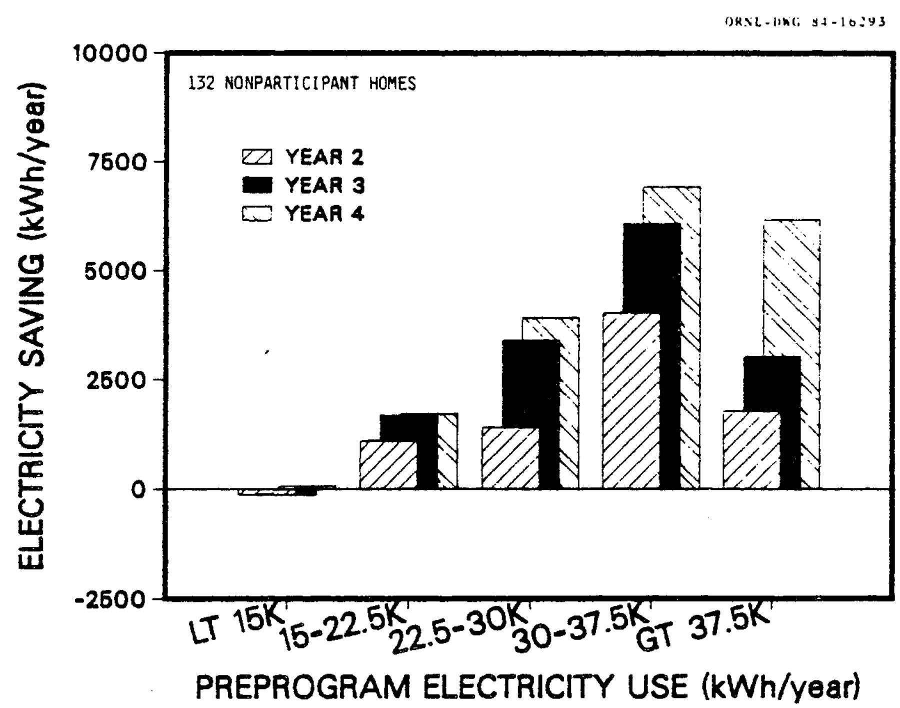

Figure 3. Reductions in Annual Electricity Use in Years 2, 3, and 4 (Relative to Year 1) as a Function of Preprogram Electricity Use (NAC_1) for Nonparticipant Households.

The substantial reduction in electricity use for nonparticipants is surely due in part to the large increases in electricity prices in the Pacific Northwest during this period. Real (net of inflation) residential electricity prices increased by 130% between years 1 and 4. It seems likely that other forces were at work during this time, which also affected household electricity use. Considerable public awareness of energy issues, knowledge of the potential for saving money through adoption of energy conservation practices and measures, changes in household income, and overall changes in the region's economy may all have influenced household electricity use.

ENERGY ANALYSIS: CROSS-SECTION MODEL

We next used NAC results to estimate a cross-section model. That is, for each household, values of NAC for the four years are the dependent variables. This ensures that the observations for each household are for the same time periods and are adjusted for differences in winter severity. The purpose of this model is to analyze variations in annual weather-adjusted electricity use as a function of household demographic and structure characteristics and participation in the BPA program.

Explanatory variables include household income, number of household members, floor area, annual wood use, primary heating fuel, electricity price and dummy variables for program participation (Table 2).* The strength of this approach, relative to the preceding one, is the explicit incorporation of many factors that affect electricity use, both pre- and post program.

We used the SAS (1983) procedure TSCSREG (time-series/cross-section regression) to estimate this model. This procedure accounts for the correlation among the four NAC terms for each household (i.e., it explicitly recognizes that the observations are not independent of each other for each household).

This model (with 349 households x four years, 1396 observations) explains 37% of the variation across households in NAC (Table 2). Almost all the coefficients are statistically significant at the 1% level or better. Only the dummy variables for the AO households in years 1 and 4 are not significant at reasonable levels.

The model shows that normalized annual electricity consumption increases with household income, number of household members, floor area and use of

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*The AL and AO binary variables are one for the AL and AO households, respectively, for both pre- and post-program periods. AL*year j and AO*year j are equal to one for AL and AO households, respectively, in year j only (j = 2,3,4). The first pair of binary variables captures preprogram differences in electricity use among groups and the other pairs capture differences in electricity savings among groups.

Table 2. Regression Results (Coefficients) for Stage-Two Model of NAC (kWh/year)[a]

Explanatory variable	Model coefficient	Significance level
Intercept	12,300	0.00
Income ($)	0.145	0.00
No. of household members	1,700	0.00
Floor area (ft^2)	3.93	0.00
Wood use (cords/year)	-415	0.02
Electricity price (¢/kWh)	-2,720	0.00
Binary variables		
Electricity is primary heating fuel	4,090	0.00
Audit + loan (AL)	2,340	0.01
AL*year 2	-4,480	0.00
AL*year 3	-4,260	0.00
AL*year 4	-4,170	0.00
Audit only (AO)	1,670	0.24
AO*year 2	-1,870	0.02
AO*year 3	-1,890	0.02
AO*year 4	-1,130	0.18

[a]Based on 1396 observations (349 households x four years); R^2 = 0.37.

electricity as the primary heating fuel.* Electricity consumption is inversely related to wood use and electricity prices.

The insignificance of the AO coefficient supports our earlier finding that the AO and NP households are much alike in terms of preprogram electricity use. The postprogram dummies for AO households show a significant savings due to the BPA program in years 2 and 3 of 1900 kWh/year. However, the program-related saving in year 4 is not significantly different from zero.

The AL dummy is highly significant and indicates that, all else being equal, audit + loan households use 2300 kWh/year more than either the AO or NP households. The reductions in postprogram electricity use for the AL households are also very significant; their coefficients show savings of 4500 kWh/year in year 2, 4300 kWh in year 3, and 4200 kWh in year 4 due to participation in the BPA pilot program.

*Because virtually all these homes use electricity for some space heating, this dummy variable reflects the additional electricity used for primary heating relative to homes that use electricity only for supplemental heating.

DYNAMICS OF PROGRAM ENERGY SAVINGS

We developed a very simple simulation model to estimate the likely future effects of the BPA pilot program. The model computes total and net electricity savings for program participants as a function of electricity prices and time (Hirst, White and Goeltz, 1985).

Model results, assuming that real electricity prices remain constant after 1984, suggest that the total saving for these 1981 participants increases to 6700 kWh five years after participation and to 7000 kWh after ten years. Comparable estimates of the net (program-induced) savings are 3800 kWh and 3600 kWh. The long-run net saving due to the BPA pilot program under this scenario, 3600 kWh, is 80% of the net saving the first year after participation (Figure 4).

If electricity prices increased after 1984, then the total saving for both participants and nonparticipants would increase more rapidly. But the net saving would decrease more rapidly and to a lower long-run level. On the other hand, if the pilot program had been operated at a time when electricity prices were stable, net energy savings would have been larger than calculated in the above scenario.

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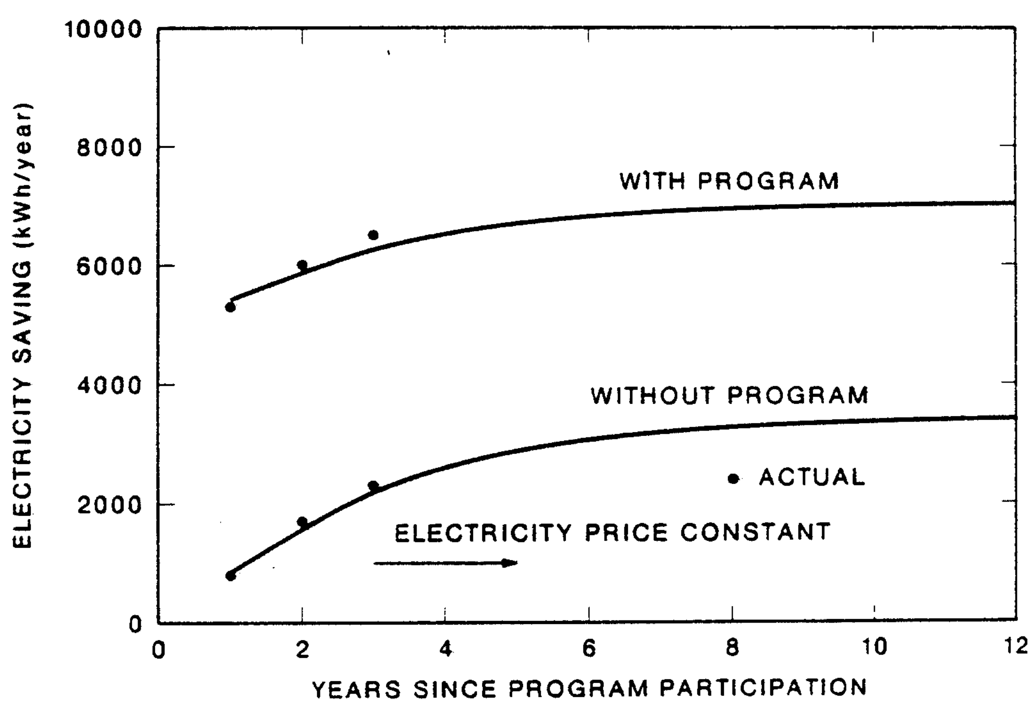

Figure 4. Electricity Savings Due to the BPA Pilot Program Assuming No Further Electricity Price Increases After 1984.

CONCLUSIONS

A two-stage method was used to estimate the energy saving directly attributed to the BPA Residential Weatherization Pilot Program. The first stage, development of simple PRISM models for each household, controls for variation in outside temperatures (i.e., winter severity). This model does not adjust for other factors that affect household electricity use. The second stage, which uses the stage one results in a pooled time-series/cross-section analysis, explicitly accounts for some economic, demographic, and structure differences among households.

Our best point estimates of the net program savings (based primarily on the cross-sectional model) are: 4500, 4300, and 4200 kWh/year for the AL households in years 2, 3, and 4; and 1900, 1900, and 1100 kWh/year for the AO households. The comparable total energy savings are 5300, 6000, and 6500 kWh/year for the AL households; and 3000, 4400, and 4100 kWh/year for the AO households.

We think the results for the AL households are credible. They show that program-induced electricity savings diminish slowly during the first three years after BPA-financed weatherization by almost 10% (from 4500 to 4200 kWh/year). This decline occurs because the primary effect of the program is in year 2 (immediately after retrofit) while the effects of rising electricity prices and other factors are felt each year. This suggests that, even without the BPA program, these households would ultimately have installed at least some of the measures financed by the BPA program. However, the program yields dramatic energy savings for at least a few years after participation.

Results for the audit only households are not as clearcut. Ambiguity in their estimates of energy saving occurs because the effect of the program is less on the AO than on the AL households and because the number of AO households in the present data set is small (38). Our results suggest that program-induced energy savings for the AO households are 1900 kWh/year in years 2 and 3, and then decline sharply to 1100 kWh/year in year 4. Not surprisingly, the effect of an audit only is substantially less than the effect of the audit plus loan.

These results demonstrate the importance of measuring the effects of conservation programs for at least several years after participation. If utilities purchase "conservation resources" as cost-effective alternatives to conventional supply resources, they must have confidence in the durability (persistence over time) of these energy-efficiency improvements. Results developed here, based on three years of post-participation electricity billing data, show that the energy savings directly attributed to the BPA pilot program are substantial and diminish only slowly during this initial three-year period.

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