Stability and Persistence of Savings in Residential Homes

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Persistence and variability of energy savings are important issues in the long-term reliability of acquired DSM resources and their cost-effectiveness. During 1982 and 1983, the Bonneville Power Administration sponsored the Interim Residential Weatherization Program (IRWP). Implemented by approximately 96 regional utilities, IRWP provided home energy audits and financial assistance for installing energy conservation measures to 104,000 residences in the Pacific Northwest region served by Bonneville. A sample of participant and non-participant households have been studied over time, with six years of post-weatherization energy use data available. Analysis of the persistence of energy savings, characteristics of high energy savers, and the stability of energy savings of individual households are discussed.

Introduction

During 1982 and 1983, the Bonneville Power Administration sponsored the Interim Residential Weatherization Program (IRWP). Implemented by approximately 96 regional utilities, IRWP provided home energy audits and financial assistance for installing energy conservation measures to 104,000 residences in the Pacific Northwest region served by Bonneville (Hirst et al. 1985). Measures which were eligible under the program were, for the most part, targeted at space and water heating loads, and consisted primarily of insulation and infiltration measures.

Energy and demand savings estimates of energy conservation measures (ECMs) installed during a conservation program have an expected savings attached to them. These expected savings are typically derived from engineering models based on a variety of behavioral and physical assumptions. Savings estimates of ECMs obtained by measuring actual energy consumption can deviate from these expected savings when one or more of the assumptions are violated. Generally, violation of the assumptions are due to such things as mis-specification of utilization rates and schedules of energy using equipment, inaccurate estimates of measure life, and incorrect measurement of the efficiency ratings of installed and replaced equipment.

Engineering savings estimates are static in the sense that the base level ("current practice") of energy efficiency in existing equipment from which savings estimates are calculated are constant over the life of the installed measures. The engineering estimates are thus a measure of the total savings. If the net savings are of interest, then the "current practice" of energy conservation or level of energy savings the participants would have saved independent of the program need to be estimated.

Methods commonly used to obtain alternative savings estimates, which are more flexible than engineering models, use a combination of actual consumption data, comparison/control groups, and a variety of statistical techniques coupled with customer data. Often the use of short-run (one year pre-installation and one year post installation) data will capture changes due to equipment use, inexact specifications of efficiency ratings, and other structural, operational and behavioral changes. Using a control group allows for changes in the base use levels captured and, therefore, net program savings to be estimated. Finally, statistical techniques can be used to control for other major short-term changes.

How these savings change over time is not well understood. Certain violations in the engineering models' assumptions of savings will not be detected in the first or second year after ECM installation. Incorrect savings estimates due to inaccurate efficiency rates can be corrected by analyzing the first year of post-installation energy consumption, while physical deterioration and a concomitant decrease in average measure life, due to either poor quality of manufacture or installation of the ECM, may only be noticeable after a fairly lengthy period of time. The use of a comparison group should control for behavioral, equipment, and structural changes which are assumed to be the same between groups. However, the comparison group consumption is not necessarily static. Changes in the comparison group consumption will affect net program savings on an annual basis.

Methodology

To research some of the issues which are discussed above, this study focuses on seven years of electric consumption for residential customers at nine utilities in the Pacific

Northwest. These customers are separated into two groups: participants residing in single family homes who took part in Bonneville Power Administration's Interim Residential Weatherization Program (IRWP) and were weatherized in spring 1983, and a group of non-participants. The sample used is a sub-sample of the group of participants and non-participants which have had their electricity use analyzed in previous studies (Hirst et al. 1985; Goeltz et al. 1986; Ecker et al. 1991).

To obtain energy consumption with which to make comparisons between groups and over time periods, billing data was weather-normalized and annualized. Weather-normalized annual consumption (NAC) estimates are obtained through the use of the Princeton Scorekeeping Method (PRISM)(Fels 1986). Not all the models which were estimated with PRISM provided adequate results due to anomalous parameters such as a negative heating slopes and/or base load or low explanatory power (R2). For those households and times periods in which PRISM results were not adequate, a second estimation procedure was used.

A simple regression model was developed to predict NAC using annualized actual consumption and binary variables for two of the three distinct climate zones in the study area. Annual models were estimated for each of the seven years using those households which had satisfactory PRISM NACs. All of the seven annual models explained more than 98% of the variation in weather-normalized electric consumption in each year. NACs were calculated by substituting actual values into the models for those households and time periods which had unacceptable PRISM results. This allowed the analysis to be conducted on a consistent cross-section time-series sample, for which seven years of consumption and six years of savings estimates are present.

Annual gross savings are obtained by subtracting the NAC of the post-installation period from the pre-program NAC. The annual periods are for the post-program heating seasons of 1984-1985 to 1989-1990 and the pre-program base year of 1982-1983. Net savings are estimated by subtracting the mean annual changes of non-participants from that of the participants. Households, which were deemed outliers due to extreme consumption levels and excessive fluctuations in consumption, were then removed from this sample.

Analysis

The analysis of net annual savings has been covered in an earlier study (Ecker et al. 1991). However, interest in program effects should not just be centered on overall average savings, but savings of specific groups of participants and the stability of these savings. The result of targeting customers having both high and stable savings would aid in the success of a DSM program. In the following two sections, we will examine the stability of energy consumption levels over the seven-year study period. Certain rudimentary information is available on the IRWP sample. This information on building and household characteristics stems from surveys conducted in 1983, and is of only limited value.

Average Savings

By separating the sample into seven groups by the level of the average annual change in consumption over the seven-year study period, one can clearly observe that there is a correlation between reductions in consumption and the level of initial base year consumption (Table 1). The only exception to this pattern is the group of participants and non-participants who, on average, increased their consumption the most. The few household characteristics variables which were available, such as the age of the building, the area, the initial number of occupants, or the initial level of income, were found to have little correlation with the level of average savings. The hypothesis that the largest users have the most to save and thus will be responsible for most of the savings seems to be confirmed by these findings.

Comparisons of participants and non-participants by level of base use exhibits results which may cancel the conclusion just reached above. Participants with a base electricity consumption over 31,000 kWh have average annual gross savings of 4,700 kWh, over 1,100 kWh more than the next closest grouping. However, when compared with their non-participant cohort, the net savings could be calculated as being only 1,600 kWh, which is lower than the net savings of the customers with consumption between 21,000 and 31,000 kWh (Table 2). Thus, the hypothesis should perhaps be modified by stating that even though participants with high levels of energy use may reduce their consumption the most when participating in a DSM program, much of this reduction would have occurred independent of program participation.

When comparing participants and non-participants cohorts with lower base energy consumption, little net savings are calculated for the participants consuming less than 21,000 kWh. This would indicate that households with lower levels of energy use are not responsible for much of the program savings. This does not mean that these households should not have participated in a DSM program, but that a retrofit program, which IRWP was, may not have been the most appropriate type of program for this group.

Table 1. Average Six Year Gross Savings by Pre-Program Consumption

	Less Than -1,000 kWh	-1000 to 0 kWh	0 to 1,000 kWh	1,000 to 2,000 kWh	2,000 to 4,000 kWh	4000 to 6,000 kWh	Greater Than 6,000 kWh
Participants							
NAC 82/83							
Mean	22,962	16,248	18,754	21,804	23,037	26,472	31,109
Average Annual Gross Savings							
Mean	(2,802)	(483)	532	1,551	3,014	5,018	7,929
Valid N	37	21	20	29	39	38	39
Non-Participants							
NAC 82/83							
Mean	22,755	19,314	19,718	22,790	22,272	25,421	32,235
Average Annual Gross Savings							
Mean	(2,845)	(476)	519	1,463	2,819	5,155	7,506
Valid N	34	27	34	32	17	12	12

Table 2. Pre-Program Consumption by Average Six Year Gross Savings

	Less Than 16,000 kWh	16,000 to 20,999 kWh	21,000 to 25,999 kWh	26,000 to 30,999 kWh	Greater Than 31000 kWh
Participants					
NAC 82/83					
Mean	12,616	18,480	23,338	28,458	35,470
Average Annual Gross Savings					
Mean	895	1,082	2,328	3,591	4,689
Valid N	34	55	45	48	41
Non-Participants					
NAC 82/83					
Mean	12,633	18,392	23,294	28,050	34,296
Average Annual Gross Savings					
Mean	24	908	445	837	3,124
Valid N	40	30	44	27	27

It may be more favorable to have this type of customer take part in programs which target specific end uses such as space water heating and lighting.

Stability of Savings

The stability of energy savings is also an issue. DSM resources must be reliable to be a useful utility resource. If program induced energy reductions fluctuate erratically from year to year, expected energy and capacity savings will not be realized, and will not be well-suited to offset planned increases in generating capacity. Fluctuations in savings are analyzed in two ways: 1) ranking customers by the gross savings in consumption for each post-program year, and tracking these rankings over time; and 2) analyzing the variation in changes in consumption of individual homes.

Ranking. Participant and non-participant groups are tracked by ranking the reductions in consumption, for each post-retrofit year as compared to the pre-program consumption, and separating the two groups into quintiles for each year. For the participants, this reduction can be interpreted as the gross electricity savings induced by the program, and for the non-participants, it is the energy savings which arose due to factors other than program participation. These five groups of households with the lowest savings to highest savings in the first year of the program are tracked through subsequent years by their average ranking. This reveals if high savers tend to remain high savers, and if low savers tend to remain low savers. If individual customer changes in consumption were random, then one would detect a total regression towards the mean after the first year. The mean rank of those customers belonging to each quintile for changes in consumption in 1984 does not change to a mean of three in the next year or following years of the study for either the participant or non-participant group (Figures 1 and 2).

Customers who were ranked in cohorts with larger savings in the first year after retrofit tended to keep on ranking in those cohorts over the six-year period. The same is true for those customers who had low savings, or even increased their consumption in the first year. For participants, high savers tended to remain high savers while those participants which experienced low savings tended to remain low savers. From the graphs presented, it is clear that there is some regression towards the mean for households, which is more pronounced in the non-participants. It is possible that if additional years of consumption were analyzed, the average rankings of the quintiles would equalize.

Variation in Savings

Another method to measure stability is to compare the variation in the changes in consumption of each household. With six years of gross savings estimates it is possible to calculate the standard deviation in savings for each household. Standard deviations and the standard deviation normalized by the base year consumption are absolute and relative measurements of variation. Both the absolute and normalized values are of interest. The standard deviation may be correlated with the initial level of electrical consumption and, normalization should remove this effect.

After separating the total sample into quintiles for the standard deviation and the standard deviation normalized by the pre-program level of use it is clear that the dispersion of both variables is quite similar in both participant and non-participant groups (Table 3 and Table 4). As one would suspect, the initial level of use is an important factor in determining the size of the standard deviation. This obvious correlation is removed after normalizing the standard deviation of each household by the pre-program consumption. Yet with the participants, it is seen that, on average, the households with the greatest relative variation in annual savings also have significantly lower levels of pre-program consumption and energy savings than the groups with lower relative variation. With the non-participants there are no such obvious trends.

When comparing the changes in consumption with the standard deviation, it is revealed that average savings over the six years did not significantly differ among all but the customers in the highest quintile (Table 5). This was true for both the participant and non-participant groups. In both cases, customers with the largest standard deviations had, as a group, the highest base consumption levels and the largest homes. In the case of program participants, this high variance was also coupled with the lowest six-year average in gross savings. The reverse was true for the non-participants in the highest quintile since they experienced, as a group, the largest average six-year reduction in consumption. For non-participants the variance was also positively correlated with the initial occupancy level.

Taking a closer look at the annual savings of the participants with larger normalized standard deviations reveals that the savings of the participants in the two highest quintiles are not stable (Table 6). While non-participants and the other participants groupings showed no obvious trend, those participants in the highest 40% showed a steady decline in savings over time. Except for

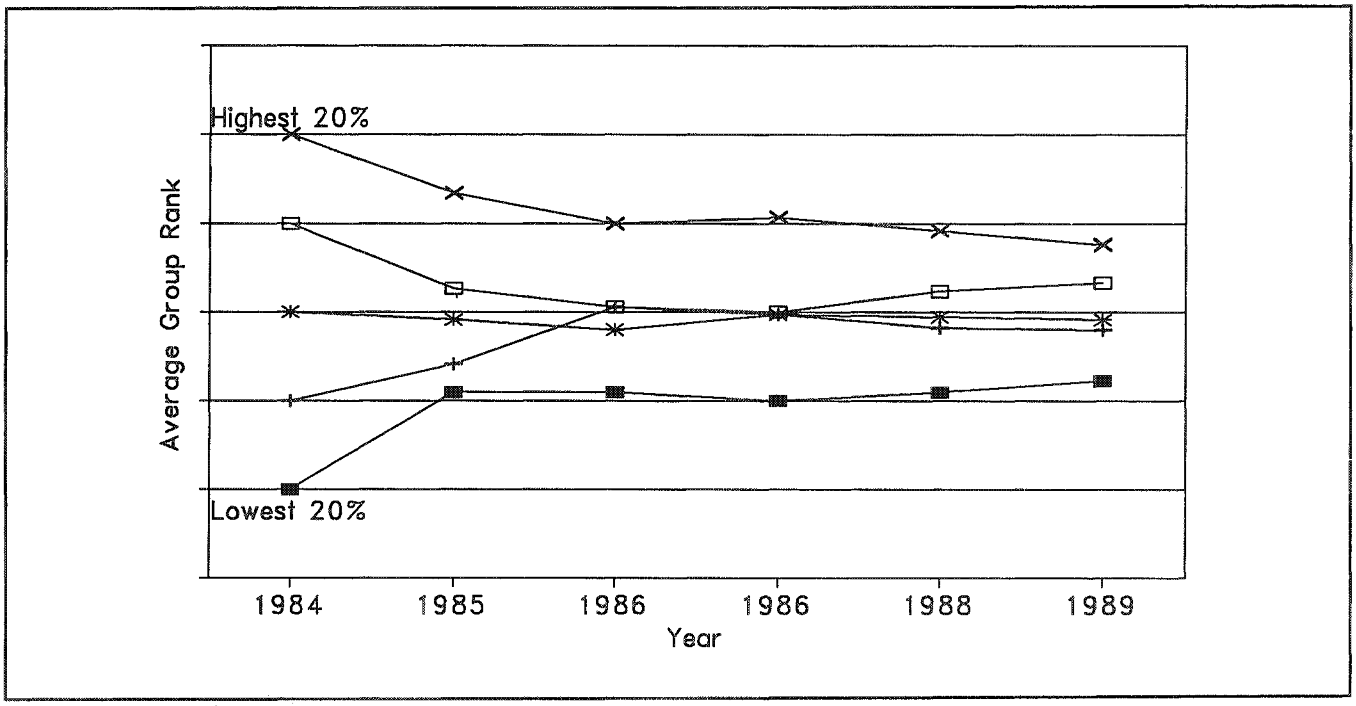

Figure 1. IRWP Annual Ranking in kWh Savings (Non-Participants N=168)

having a significantly lower level of average base year energy use, there is no clear indication from the survey data which reveals why this reduction occurred. "Take back" and other income effects may explain a portion of this trend.

Further analysis of those customers groups which experience the highest fluctuations in both absolute levels of variation and normalized levels indicates that the reliability of these savings could be called into question. Fluctuations in gross savings cover a range of over

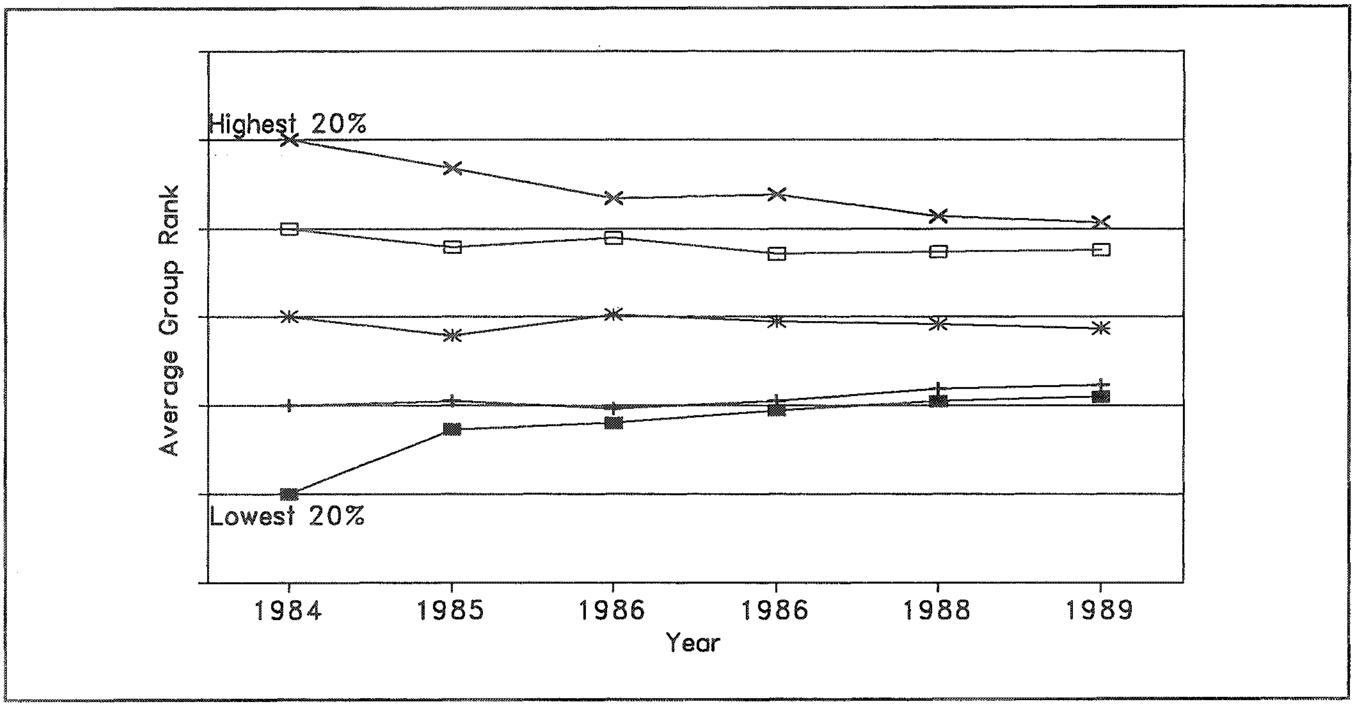

Figure 2. IRWP Annual Ranking in kWh Savings (Participants N=223)

Table 3. Standard Deviation Quintiles by Pre-Program Consumption and Average Six Year Savings

	Lowest 20%	2	3	4	Highest 20%
Participants					
NAC 82/83					
Mean	20,363	21,160	23,966	25,895	27,589
Average Annual Gross Savings					
Mean	3,125	2,564	2,523	2,829	1,508
Valid N	41	44	50	45	43
Non-Participants					
NAC 82/83					
Mean	16,415	21,314	22,600	24,546	27,656
Average Annual Gross Savings					
Mean	710	561	632	778	1,868
Valid N	37	34	29	33	35

Table 4. Normalized Standard Deviation Quintiles by Pre-Program Consumption and Average Gross Six Year Savings

	Lowest 20%	2	3	4	Highest 20%
Participants					
NAC 82/83					
Mean	24,843	24,955	26,574	22,135	20,313
Average Annual Gross Savings					
Mean	3,970	3,318	3,193	1,028	698
Valid N	44	51	46	34	48
Non-Participants					
NAC 82/83					
Mean	23,667	23,655	21,110	21,587	22,518
Average Annual Gross Savings					
Mean	811	977	1,111	1,054	593
Valid N	34	27	33	44	30

Table 5. Standard Deviation Quintiles by Annual Gross Savings

	Lowest 20%	2	3	4	Highest 20%
Participants					
Gross Electric Savings 83/84	3,036	2,389	1,914	2,676	2,971
Gross Electric Savings 84/85	3,175	2,702	2,368	3,135	1,808
Gross Electric Savings 85/86	3,331	2,860	3,048	3,529	1,983
Gross Electric Savings 86/87	3,160	2,742	2,686	2,592	1,591
Gross Electric Savings 87/88	3,095	2,604	2,682	2,765	1,040
Gross Electric Savings 88/89	2,955	2,085	2,440	2,279	(345)
Non-Participants					
Gross Electric Savings 83/84	689	435	220	227	1,109
Gross Electric Savings 84/85	772	514	(105)	388	1,311
Gross Electric Savings 85/86	686	1,255	755	2,020	2,543
Gross Electric Savings 86/87	781	588	769	1,156	2,854
Gross Electric Savings 87/88	672	435	1,135	346	2,147
Gross Electric Savings 88/89	662	136	1,016	534	1,244

Table 6. Normalized Standard Deviation Quintiles by Annual Gross Savings

	Lowest 20%	2	3	4	Highest 20%
Participants					
Gross Electric Savings 83/84	3,735	2,588	2,108	1,890	2,451
Gross Electric Savings 84/85	4,000	3,267	3,194	1,220	1,150
Gross Electric Savings 85/86	4,188	3,531	3,883	1,762	1,167
Gross Electric Savings 86/87	4,078	3,392	3,374	833	701
Gross Electric Savings 87/88	3,942	3,686	3,558	204	263
Gross Electric Savings 88/89	3,876	3,443	3,043	259	(1,507)
Non-Participants					
Gross Electric Savings 83/84	797	443	1,096	228	258
Gross Electric Savings 84/85	731	1,025	660	309	459
Gross Electric Savings 85/86	1,212	1,405	1,470	1,896	1,153
Gross Electric Savings 86/87	903	804	971	1,511	1,944
Gross Electric Savings 87/88	700	1,179	1,090	1,217	466
Gross Electric Savings 88/89	523	1,004	1,381	1,160	(724)

3,000 kWh (Table 5) for the participants with the highest standard deviations. The ranges of other quintiles are at most one-third as much. Due to the large swings in average annual savings, the program savings of this group will not be a reliable resource.

Conclusion

The results of the stability analysis coupled with that of the average savings over the six-year period lead to the conclusion that more research should be done in identifying basic characteristics of customers who have stable and high savings. The results also indicate that programs need to be targeted at specific customer groups if measures are to be cost-effective and free riders are to be avoided. When developing a program, it should be taken into account that high-usage households also have the greatest incentive to become more efficient consumers of energy, independent of the program. Setting caps on income or the level of energy use as a requirement for participation should remove many of these free riders. Care should also be taken when selecting participants with lower levels of electricity consumption. These households displayed fairly low levels of net savings and were also highly represented in the participant groups with unstable and steadily declining savings. For this type of household, it may be more effective to have them participate in less comprehensive programs.

References

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