ARE WE FIGHTING A BATTLE WE'VE ALREADY WON?

A Dynamic Regression Analysis of 17 Years of Electrical Billing Data To Determine Residential Household Usage Trends

Karen Schoch, Pacific Power & Light Company; Muhannad Khawaja, Portland State University; and H. Gil Peach, Pacific Power & Light Company

ABSTRACT

This paper is a study of trends of electricity consumption in homes with installed electric heating equipment in three Oregon communities. The analysis presented investigates the effect of various economic factors on monthly kwh usage after the effect of weather is removed.

Weather normalized billing data from 1968 to 1985 is analyzed. Factors investigated include previous month's usage, real average price, per capita income, number of home energy audits, type of rate structure, and percent of multi-family dwellings.

Results show that residential customers have voluntarily curtailed their electricity consumption since approximately 1977. The impact of this reduction in consumption on potential energy savings is discussed as it relates to residential weatherization projects.

Research supported by the Bonneville Power Administration, U.S. Department of Energy, under Contract No. DE-AC-79-83BP11287. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either express or implied, of the U.S. Government.

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INTRODUCTION

Engineering estimates of conservation potential in the residential sector are often unattainable in practice, sometimes by a large margin. One explanation of this discrepancy between actual and predicted kwh savings is that part of the savings have already occurred through self-directed customer conservation.

This paper analyzes 17 years (January 1968 - March 1985) of quasi-monthly billing data collected from three areas of Oregon: Hood River, Pendleton, and Grants Pass (Figure 1). An economic model is developed using the mean weather-adjusted kwh consumption from electrically heated homes and various factors (such as previous consumption, average price of electricity, average income, number of home energy audits, and type of rate structure) to analyze trends of average household consumption.

This study provides a unique opportunity to work with a project which included a quasi-experimental design from its conception. The Hood River Conservation Project, for which this data was originally obtained, is a $21 million project designed to research the conservation potential of super-weatherizing residential housing (PP&L, 1982 & 1983). Evaluation needs helped to tailor the design of the project database, which included time-series billing record data since 1968. This time-series dataset is unique in the sense that only a small number of utilities maintain historical billing records to this extent.

The objective of this paper is to produce an economic model which explains electricity demand in three Oregon areas: Hood River and two comparison communities. A future study will build upon this model to predict electrical demand in Hood River if the conservation project had never taken place. Other methods of model building, as discussed in BPA System Monthly Forecasting Models (Morse, 1981), will be explored in future analysis.

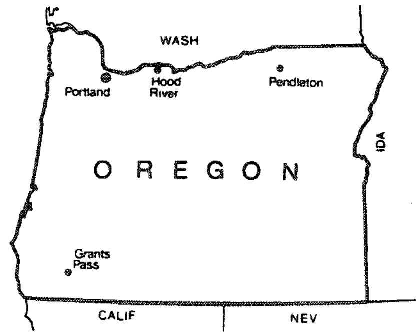

Figure 1. Location of Hood River and comparison communities.

DATA COLLECTION AND PREPARATION

The three areas analyzed in this paper were chosen for several reasons. First, Hood River (city and county) was identified in the Hood River Conservation Project Transferability Study (French et al, 1985) as being representative of the Pacific Northwest. Second, Pendleton and Grants Pass, along with their respective counties, were shown to be comparable to Hood River in a Baseline Survey (Berg & Bodenroeder, 1983). Third, by choosing areas within one state and one utility's service area, one economic factor, the price of electricity, remains constant across the areas. Fourth, Pacific Power & Light Company which serves the three areas has collected monthly consumption data since January 1968 which makes this study possible.

The data is divided into two categories: homes that use or have used electricity for heating; and homes that show a flat load shape for the past 17 years, which indicates no electric heating load.[1] The former category is analyzed in this paper.

Winter is defined as usage for December through February and summer is defined as usage for June through August. The criteria for determining electric heat use are:[2]

Demand(Winter) > Demand(Summer) * 1.3
AND Demand(Winter) > 3,000 kwh AND Demand(Summer) > 1,800 kwh

OR Demand(Winter) > 6,000 kwh

These criteria were developed by analysing actual space-heat electric use against total electric-use ratios from submetered end-use monthly load data collected for another study by the Hood River Conservation Project.

The winter/summer comparison was done for each year between 1968 and 1984. If a residence passed the criteria in any one of the years it is assumed to have electric heat equipment installed. Most residences selected consistently passed the criteria from year to year.

Although population varies from month to month, this analysis is based on 2,283 households in Hood River, 7,230 households in Pendleton, and 10,777 households in Grants Pass in January 1968. In March 1985 there were 3,296 households in Hood River, 11,965 households in Pendleton, and 17,078 households in Grants Pass.

A second selection was made of monthly kwh values greater than 150. This selection removed the effects of vacancy on the monthly group means. Only individual household months considered vacant were removed while other data for these residences were retained. Vacant home-months were removed to eliminate the artificial lowering of the community mean monthly household usage.

The resulting dataset for analysis consisted of monthly household kwh consumption and monthly billed amount for non-vacant electrically heated homes in the three areas.

Time series data was also collected for the following variables: average real price of electricity paid by customers; per capita income by county,[3] home energy audits performed in each county,[4] type of rate structure in effect,[5] and percent of multi-family dwellings.[6] Percent of multi-family dwellings was dropped from the analysis after data showed the percentages to be static from year to year within each community. The average price of electricity is the monthly billed amount of non-vacant homes divided by the monthly kwh consumption of non-vacant homes. The real average price is calculated by dividing the mean nominal price (in dollars of the day) by the consumer price index.

A rate structure dummy was used to represent the following rate structure changes: tiered vs. not tiered, flat vs. not flat, and inverted vs. not inverted. A tiered rate structure charges less for the higher increment usage blocks, while an inverted rate structure charges more for the higher increment blocks. An analysis which used each of the rate structure dummies individually showed that the inverted structure was the most significant. Only the inverted rate structure dummy was used in subsequent analysis.

ANALYSIS STRATEGY

No residential building codes regarding insulation were in effect prior to 1974. On July 1, 1974, the initial structure code for insulation went into effect, with provisions for exemption for plans already submitted.[7] This means that homes continued to be built without the code requirements for approximately six more months, or to the end of 1974. The new code called for R-19 ceiling, R-11 wall, and R-4 floor.

On March 1, 1976, floor was changed to R-9. On January 1, 1979, requirements became R-19 floor, R-11 wall, and R-30 ceiling. Effective July 1, 1986, new standards will be R-38 ceiling, R-19 wall, and R-19 floor. Because of this drastic change in Oregon residential building codes, the data was split into two parts: homes built before 1975 (pre 1975), and homes built in 1975 or later (post 1974).

After separating the data into two analysis groups, the data was weather normalized as discussed in the following section. Seasonal variation was then removed and the consumption trends were graphed (Figures 2-7). A dummy structural variable representing the change in trend direction shown in the graphs was then modeled, and is discussed in the following section. Various economic and demographic variables then were entered into the regression model, with collinearity analyzed using correlation matrices, and serial correlation examined by Durban Watson's D statistic and Durbin's H statistic for models with a lagged dependent variable.

FINDINGS

Weather Adjustment

Weather adjustment is performed to remove the effect of exceptionally warm or cold temperatures from the normal monthly usage. After the effects of weather and seasonality are removed, consumption data can be analyzed for underlying influences.

Heating degree months and cooling degree months at base 65°F were obtained from National Oceanographic and Atmospheric Administration weather stations located within each community. A heating degree month is the sum of heating degree days in a calendar month, and a cooling degree month is the sum of the cooling degree days. Weather normalized values were obtained by regressing monthly mean kwh values against heating degree months using the resulting residuals for further analysis. Results of the regression are shown in Table I, where R^2 describes the percentage of variation in the data explained by the model and alpha shows the probability of the relationship occurring by chance. The individual alpha statistics show the probability of each contributing variable's influence occurring by chance. This table shows that heating degree months are very important in explaining consumption. Cooling degree months are somewhat less important.

TABLE I. Effect of heating and cooling degree months on consumption.

AREA	Model R^2	Model Alpha	HDM Alpha	CDM Alpha
pre 75 Hood River	0.722	0.0001	0.0001	0.0411
pre 75 Pendleton	0.742	0.0001	0.0001	0.0003
pre 75 Grants Pass	0.771	0.0001	0.0001	0.0792
post 74 Hood River	0.759	0.0001	0.0001	0.1575
post 74 Pendleton	0.735	0.0001	0.0001	0.0030
post 74 Grants Pass	0.745	0.0001	0.0001	0.0794

$KWH_{Pre\ 75\ Hood\ River}$ = 836.31 + 1.11(heating degree month) + 0.08(cooling degree month) + error

$KWH_{Pre\ 75\ Pendleton}$ = 857.75 + 0.90(heating degree month) + 0.06(cooling degree month) + error

$KWH_{Pre\ 75\ Grants\ Pass}$ = 897.75 + 1.08(heating degree month) + 0.04(cooling degree month) + error

$KWH_{Post\ 75\ Hood\ River}$ = 665.80 + 1.49(heating degree month) + 0.13(cooling degree month) + error

$KWH_{Post\ 75\ Pendleton}$ = 746.19 + 1.52(heating degree month) + 0.12(cooling degree month) + error

$KWH_{Post\ 75\ Grants\ Pass}$ = 890.62 + 1.49(heating degree month) + 0.06(cooling degree month) + error

As expected, weather in the form of heating degree months is an important factor in residential electricity consumption. After the weather adjustment, only 24-28 percent of the variation in consumption remains to be explained.

Seasonal Variation

Seasonal adjustment is performed to remove the effect of normal cyclical usage patterns throughout any given year. Trends may then be analyzed independently of seasonal influence. The weather normalized values were processed through the U.S. Bureau of Census' X-11 procedure. The X-11 procedure uses a centered 12-month moving average to smooth the trend curves by removing normal seasonal variation. Output from the X-11 procedure showed that seasonality, calculated after weather normalization, contributed an R^2 of 0.98 in all three communities. Stable seasonality is present in the data at alpha level of 0.001.

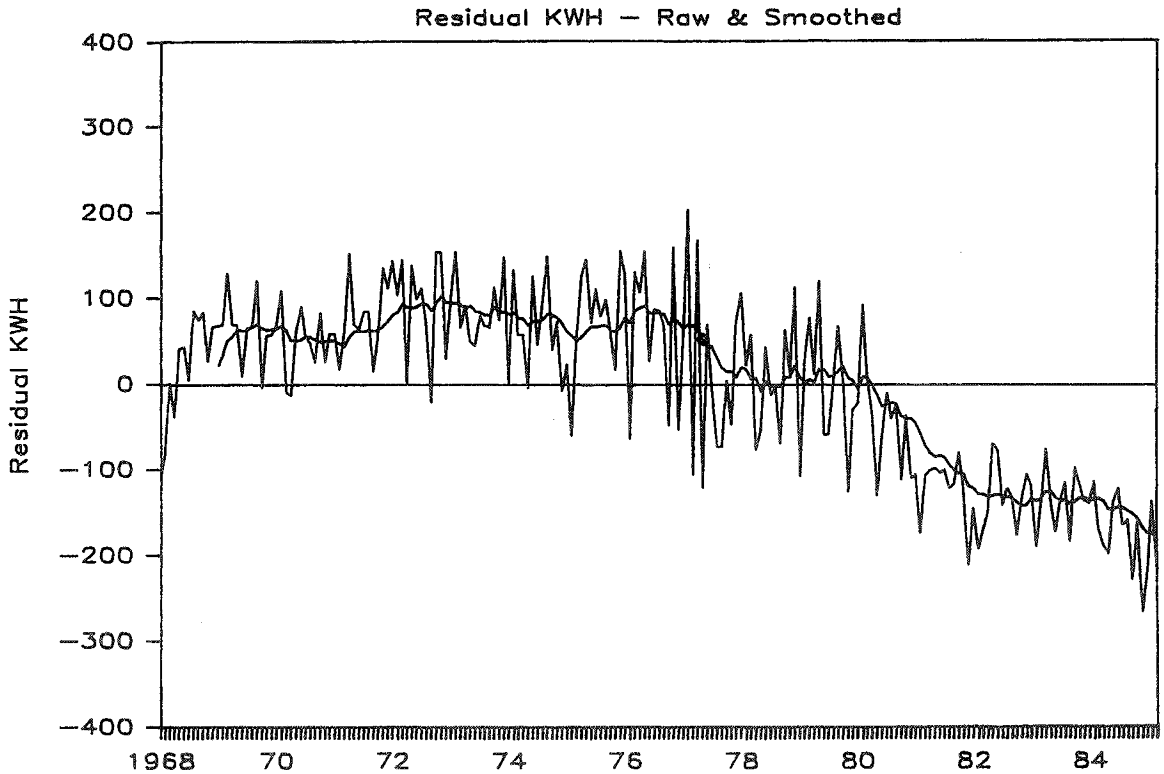

Figure 2. Hood River pre 1975 vintage housing monthly residual kwh.

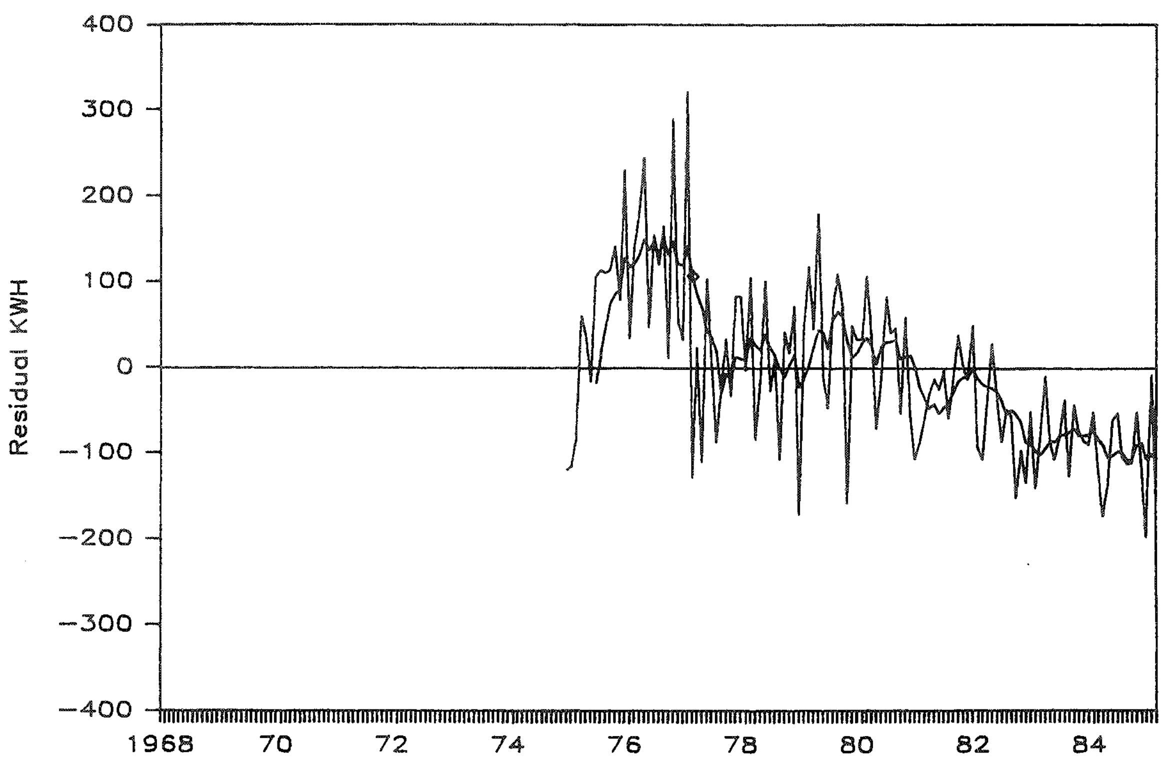

Figure 3. Hood River post 1974 vintage housing monthly residual kwh.

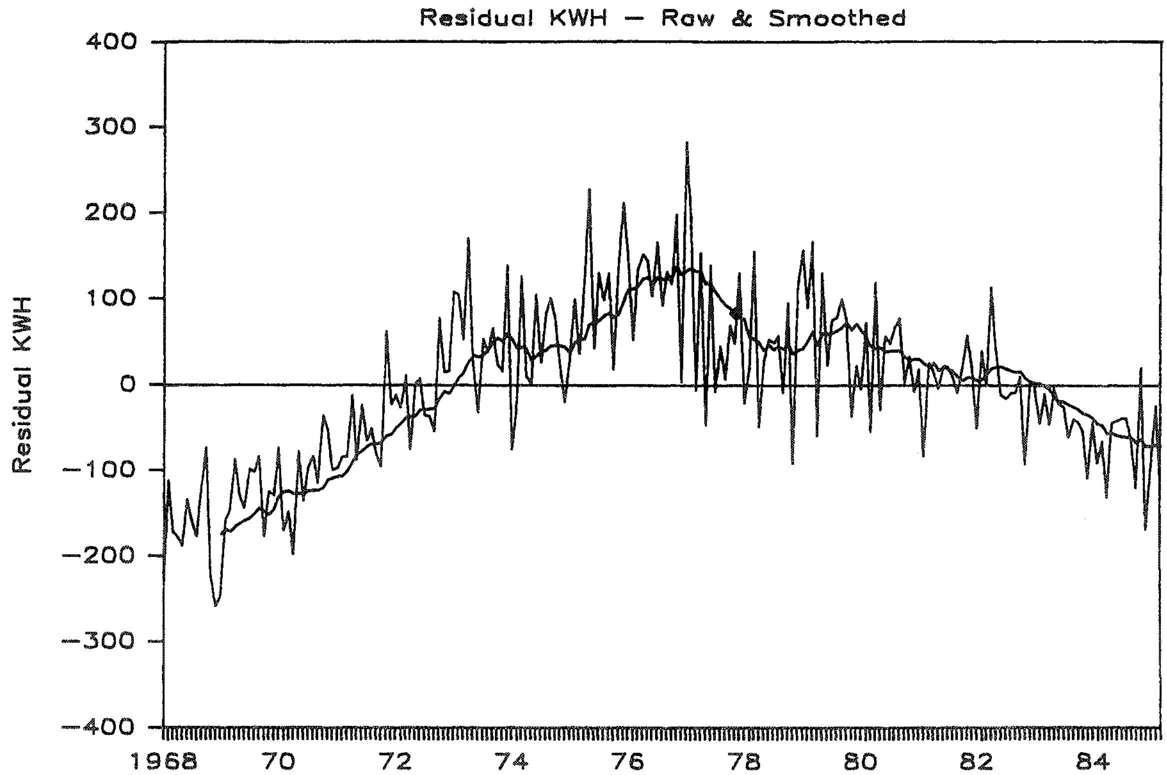

Figure 4. Pendleton pre 1975 vintage housing monthly residual kwh.

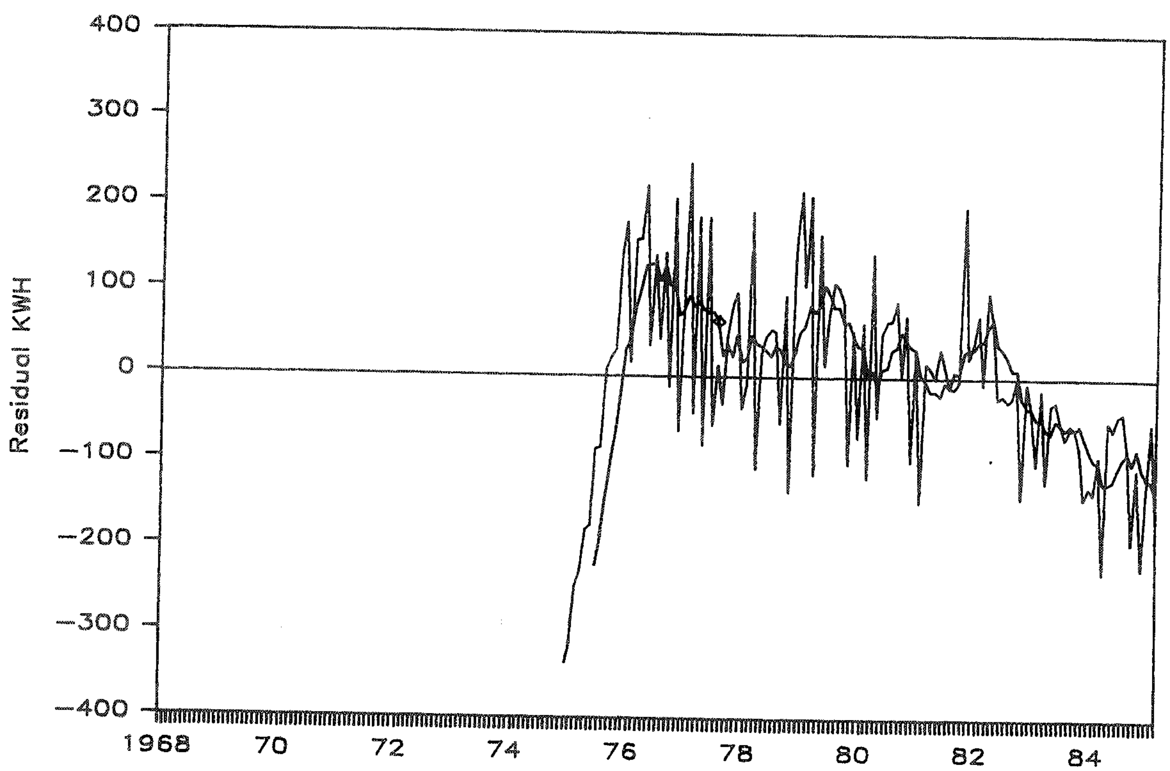

Figure 5. Pendleton post 1974 vintage housing monthly residual kwh.

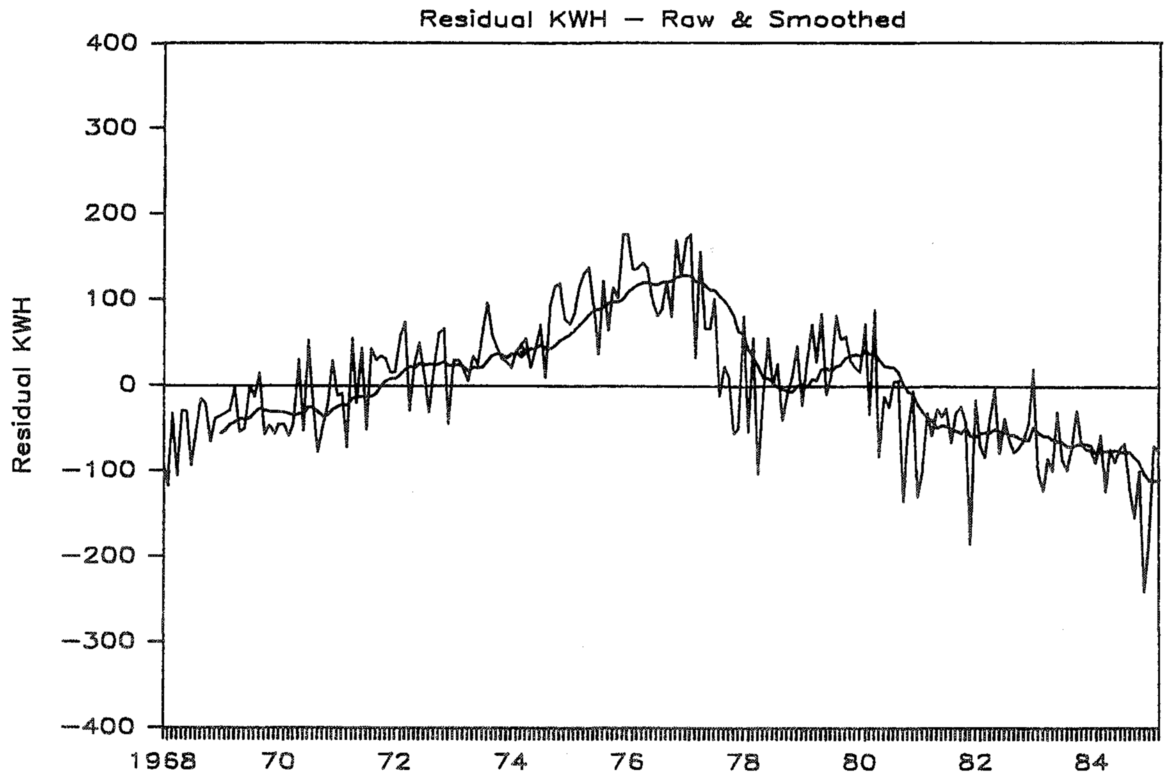

Figure 6. Grants Pass pre 1975 vintage housing monthly residual kwh.

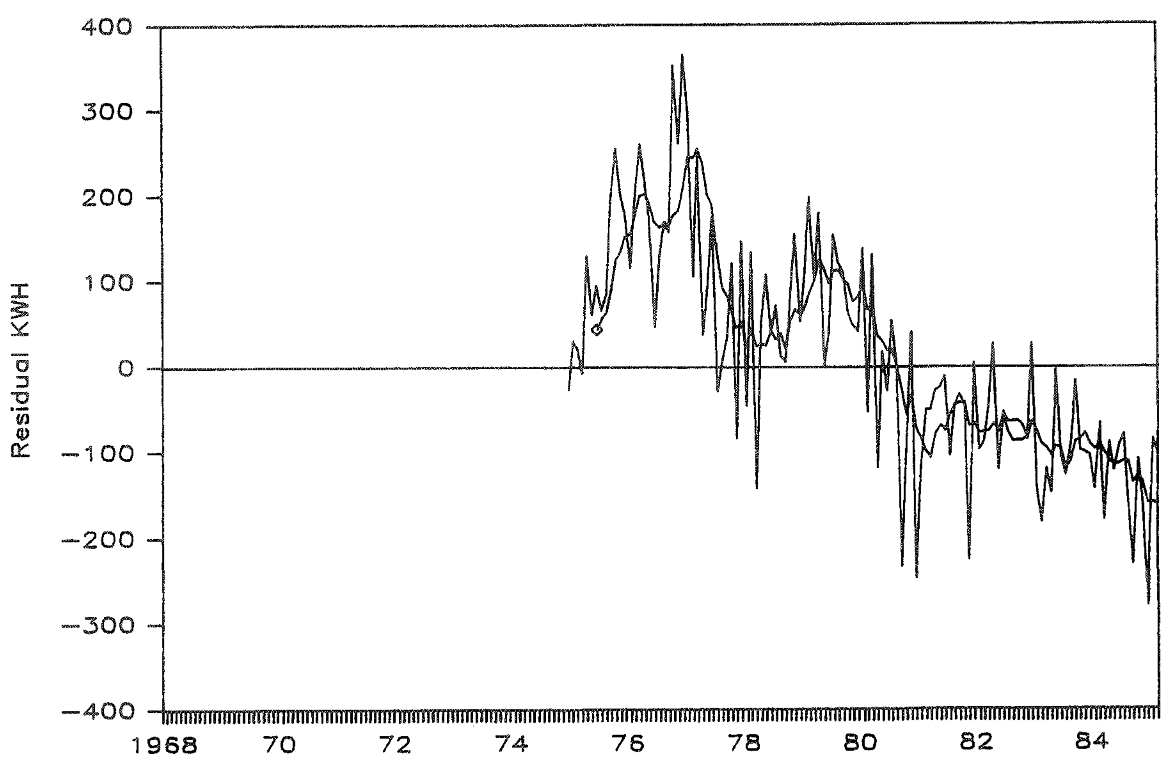

Figure 7. Grants Pass post 1974 vintage housing monthly residual kwh.

Structural Change in Trend of Consumption

Based on visual inspection of Figures 2-7, consumption patterns changed from an upward trend between 1968-76 to a downward trend starting in 1977. Preliminary analysis using December 1976 as the point of trend change showed that there was a significant structural change in electricity consumption.

A finer inflection point definition was found by using monthly mean residual kwh in regression against a dummy structure variable. The dummy variable was adjusted until the month was identified which had the maximum R^2 for each community. These points were identified as May 1977 in Hood River (R^2 = 0.505), November 1977 in Pendleton (R^2 = 0.218), and March 1974 in Grants Pass (R^2 = 0.247). The Grants Pass inflection point is unusual in two respects. First, it occurs much earlier than the other two communities, indicating that there is a factor affecting the consumption in Grants Pass which is not affecting the other two communities. The second unusual aspect is that a visual inspection of the graph would place the inflection point much later, sometime in the neighborhood of 1977. The earlier inflection point may be a result of the comparatively large cyclical behavior in Grants Pass as opposed to Hood River and Pendleton.

A second method of analysis of structure used "time" to explain variation. "Time" represents the number of months elapsed since the start of the series, with January 1968 equal to one. Mean monthly kwh was regressed against the variables "time", "time squared", and "time cubed" to confirm the existence of a parabolic or higher level curve.

Table II shows that time together with the squared value of time is an important variable combination in explaining the non-linear trend in consumption in homes built before 1975. This table shows the data has a parabolic shape with a negative trend change, confirming the presence of the inflection points discussed above. Time cubed, while significant both individually and in conjunction with time and time squared, added only a minimal amount of explanation.

Table III shows that the trends in homes built after 1974 are more linear, with time contributing the majority of the explanation in Hood River and Pendleton. In Grants Pass, however, time squared contributed a considerable amount of explanation, again suggesting that some factor is influencing Grants Pass to a greater extent than Hood River or Pendleton.

TABLE II. Pre '75 vintages incremental R^2 of time, $time^2$, and $time^3$, measured by number of months from beginning of time series.

Area		Individual R^2	Cumulative R^2	Delta R^2	Model Alpha
Hood River	Time	0.509	0.509	0.509	0.0001
	$Time^2$	0.635	0.690	0.181	
	$Time^3$	0.662	0.703	0.013	
Pendleton	Time	0.072	0.072	0.072	0.0001
	$Time^2$	0.189	0.572	0.500	
	$Time^3$	0.268	0.580	0.008	
Grants Pass	Time	0.083	0.083	0.083	0.0001
	$Time^2$	0.009	0.642	0.559	
	$Time^3$	0.001	0.645	0.003	

$$KWH_{Hood\ River} = -5.05 + 3.49(Time) - 0.04(Time^2) + 0.00007(Time^3) + error$$

$$KWH_{Pendleton} = -104.95 + 4.23(Time) - 0.03(Time^2) + 0.00004(Time^3) + error$$

$$KWH_{Grants\ Pass} = -232.65 + 6.09(Time) - 0.03(Time^2) + 0.00003(Time^3) + error$$

TABLE III. Post '74 vintages incremental R^2 of time, $time^2$, and $time^3$, measured by the number of months from beginning of time series.

Area		Individual R^2	Cumulative R^2	Delta R^2	Model Alpha
Hood River	Time	0.343	0.343	0.343	0.0001
	$Time^2$	0.355	0.356	0.013	
	$Time^3$	0.330	0.369	0.013	
Pendleton	Time	0.519	0.519	0.519	0.0001
	$Time^2$	0.514	0.525	0.006	
	$Time^3$	0.461	0.556	0.031	
Grants Pass	Time	0.066	0.066	0.066	0.0001
	$Time^2$	0.134	0.292	0.292	
	$Time^3$	0.166	0.346	0.054	

Table III. (Continued)

$$KWH_{Hood\ River} = 40.84 + 2.58(Time) - 0.07(Time^2) + 0.0003(Time^3) + error$$
$$KWH_{Pendleton} = 89.08 + 4.50(Time) - 0.13(Time^2) + 0.0007(Time^3) + error$$
$$KWH_{Grants\ Pass} = -151.87 + 12.30(Time) - 0.19(Time^2) + 0.0008(Time^3) + error$$

Explanation of the Trends Using Economic Variables

Regression of economic variables originally took the form: Mean kwh = Intercept + A_1(lagged kwh) + A_2(real average price) + A_3(real per capita income) + A_4(# home energy audits) + A_5(rate structure dummy) + error. The final models presented below contain only those dependent variables found to be significant.

Results from the regressions in the pre 1975 houses (Table IV) showed that the previous month's usage had a positive effect on consumption in Pendleton, but was not a factor in Hood River or Grants Pass. The real average price of electricity had a negative effect on usage in all three communities, while income had a positive effect across the board. The number of home energy audits helped to lower consumption in Hood River, had no effect in Pendleton, and had a positive effect in Grants Pass. The inverted rate structure dummy, which showed more influence than either the tiered or flat rate structure dummies, had a negative effect in Hood River and Pendleton, but no effect in Grants Pass. Grants Pass also had a negative intercept point.

Table IV. Pre '75 household regression equations of economic variables.

Hood River KWH = 163.55 - 2.23E6(price) + 4.03(income) - 47.02(# HEA) - 131.21(inverted rate dummy) + error
R^2 = 0.689, alpha = 0.0001

Pendleton KWH = 20.14 + 0.39(previous month's kwh) - 1.24E6(price) + 4.37(income) - 33.37(inverted rate dummy) + error
R^2 = 0.580, alpha = 0.0001

Grants Pass KWH = -259.18 - 3.44E6(price) + 23.78(income) + 31.70(# HEA) + error
R^2 = 0.550, alpha = 0.0001

For the post 1974 housing (Table IV), the previous month's usage again showed a positive effect in Pendleton, and also in Grants Pass. The real average price of electricity and number of home energy audits had a negative effect in Hood River and Pendleton, but no effect in Grants Pass. Income was not a factor in any of the communities. The inverted rate structure had a negative effect in all three communities.

Table V. Post '74 household regression equations of economic variables.

Hood River KWH = 364.19 - 2.57E6(price) -24.47(# HEA)
- 76.91(inverted rate dummy) + error
R^2 = 0.364, alpha = 0.0001

Pendleton KWH = 264.28 + 0.37(previous month's kwh)
- 1.63E6(price) - 32.35 (# HEA)
- 73.74(inverted rate dummy) + error
R^2 = 0.571, alpha = 0.0001

Grants Pass KWH = 20.92 + 0.29(previous month's kwh)
- 60.44(inverted rate dummy) + error
R^2 = 0.202, alpha = 0.0001

The differences in variable behavior between the pre 1975 vintage homes and homes built in 1975 or after are interesting. In Hood River, the previous month's kwh usage had no effect on either group. The real average cost, number of home energy audits, and the inverted rate structure showed a negative effect in both groups. Income had a positive effect on the pre 1975 houses, but showed no effect on the newer homes.

In Pendleton, the previous month's kwh usage had a positive effect on both groups. As in Hood River, the real average price and the inverted rate structure showed a negative effect on all houses. The number of home energy audits had no effect on the older homes, but showed a negative effect on post 1974 housing. Income showed a positive effect on homes built before 1975, but no effect on those built later.

Grants Pass showed a positive effect from the previous month's consumption in the post 1974 housing, but no effect on the pre 1975 group. The real average price of electricity showed a negative effect on the older homes, but no effect on the newer ones. Income had a positive influence on the pre 1975 group, but no influence on the post 1974 homes. The number of home energy audits showed an anomalous positive influence on the pre 1974 homes, but no influence on those built later. The inverted rate structure did not affect homes built before 1975, but had a negative effect on the post 1974 group. As the explanation of kwh consumption contributed by the model for the post 1974 housing is quite small, it is expected that another factor is exerting influence in Grants Pass, and needs to be identified through further analysis.

An inspection of individual variable behavior (Table VI) shows that the previous month's usage (lagged kwh) had a positive influence in half of the cases and no influence in the other half.

The real average price of electricity showed a negative influence in five out of the six equations. Only the newer homes in Grants Pass were not affected. Income showed a positive effect in all three communities on homes built before 1975, but no effect on those built after 1974.

The number of home energy audits performed per year had a negative effect on consumption in three cases: Hood River pre 1975 and post 1974, and Pendleton post 1974. There was a positive influence in Grants Pass homes built before 1975, and no influence on Pendleton pre 1975 homes or Grants Pass post 1974 homes. The positive influence on Grants Pass older homes is most likely an indication of another factor occurring in parallel, and not a true assessment of the effect of home energy audits.

The inverted rate structure, in which the larger incremental usage blocks of electricity are more expensive, influenced the decreased use of electricity in all groups except Grants Pass homes built before 1975.

Durban Watson's D statistic was calculated for each of these equations that did not contain a lagged variable, and all showed absence of auto correlation in the residuals. The Durban's H statistic was calculated for those models containing a lagged dependent variable, and a slight serial correlation was found in these three cases. Future analysis will include an auto regressive modeling procedure to correct for this correlation. Correlation matrices for each set of variables used in the equations also passed, with no variable combinations highly correlated.

Table VI. Coefficient signs and alpha levels of significant economic variables for each model.

Area	Lag kwh (1 mon.)	Average Real Price	Average Income	# of HEAs	Inverted Rates
Pre 1975 Hood River		(-) 0.0001	(+) 0.0182	(-) 0.0001	(-) 0.0001
Pre 1975 Pendleton	(+) 0.0001	(-) 0.0002	(+) 0.0024		(-) 0.0033
Pre 1975 Grants Pass		(-) 0.0001	(+) 0.0001	(+) 0.0001	
Post 1974 Hood River		(-) 0.0002		(-) 0.0136	(-) 0.0001
Post 1974 Pendleton	(+) 0.0001	(-) 0.0013		(-) 0.0047	(-) 0.0013
Post 1974 Grants Pass	(+) 0.0007				(-) 0.0035

CONCLUSION

A significant trend of increasing weather adjusted, deseasonalized electricity usage was found between 1968 and 1977, and a significant trend of decreasing weather adjusted, deseasonalized electricity usage was found between 1977 and 1985 for both groups of homes.

The previous month's consumption of electricity is not a factor of kwh consumption in Hood River housing, but is a factor in Pendleton housing. In Grants Pass, the previous month's consumption is a factor in homes built after 1974, but not for those built before 1975.

The real average price of electricity, defined as the monthly mean billed amount divided by the mean monthly consumption and then by the consumer price index, has a negative influence on consumption in all groups except Grants Pass homes built after 1974, where it has no effect.

Household income is a consistent predictor of electricity usage for older homes, those built before 1975. In newer homes, those built after 1974, income is not a factor.

The number of home energy audits performed per year has a negative effect on electricity consumption in Hood River homes and in homes built after 1974 in Pendleton. In homes built after 1974 in Grants Pass and for homes built before 1975 in Pendleton, the factor shows no influence. For Grants Pass homes built before 1975, the number of home energy audits performed has positive influence. This anomalous result in Grants Pass is most likely caused by a factor unrelated to home energy audits.

The inverted rate structure shows a negative influence on consumption in all groups except Grants Pass homes built before 1975, where it shows no effect.

Results of the economic variable analysis show that Hood River and Pendleton behave very similarly to the price of electricity, household income, and the inverted rate structure. There is some similarity in response to the number of home energy audits performed. Pendleton homes are responsive to the previous month's kwh consumption, whereas Hood River homes are not.

A comparison of Hood River and Grants Pass shows more differences than similarities. Household income is the only variable that behaves consistently between these two communities. This indicates that Grants Pass households have a different set of influences on electricity consumption than do Hood River or Pendleton. Because of this, further research must be performed before consumption in Grants Pass can be directly compared to consumption in Hood River.

This difference suggests that Pendleton be considered the primary comparison community for Hood River Conservation Project data analysis, with less weight given to comparison between Hood River and Grants Pass.

There are, however, many ways to interpret these results, in part because the explanatory factors move together in a period of structural change.

This analysis presents confirmation that customers are actively conserving electricity, and have been doing so since approximately 1977. This trend will adversely affect background corrected "savings due to program" of residential weatherization programs conducted in this era, since some of the estimated savings predicted by engineering heat loss models will already have been realized through customer action. Factors affecting this reduction in electricity usage are the average price of electricity and the inverted rate schedule. A contributing factor to a lesser degree is the number of home energy audits performed per year. Other factors, such as the use of wood heat, room closures, and other behavioral changes must be investigated before definitive conclusions can be reached.

FUTURE ANALYSIS

1) Perform further research on Grants Pass factors affecting consumption to determine why Grants Pass households do not respond the same way as households in Hood River and Pendleton.

2) Collect data on these three communities until June 1986. Plot a trend line from January 1977 to December 1983. Use Pendleton and Grants Pass to predict consumption for 1984 and 1985, and compare the actual weather adjusted deseasonalized usage data to the predictions to validate the model. If the models are able to predict actual consumption within acceptable limits, then estimate Hood River consumption with and without Hood River Conservation Project influence, which started at the beginning of 1984.

3) Analyze as #1 above, but use prior years' 12-month moving average estimate of "trend-cycle" to project weather-adjusted, deseasonalized consumption for Hood River for year through June 1986.

4) Compute analysis as in #2 above, but disaggregate into participant and non-participant homes in Hood River.

5) Conduct a parallel analysis of homes without installed electric heating equipment.

6) Repeat analysis using Princeton Scorekeeping Method (PRISM) estimates of baseload.

7) Control for housing vintage.

8) Conduct a parallel analysis using only single family homes.

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ACKNOWLEDGEMENTS

The authors wish to recognize Kenton Corum and Tom Foley from the Northwest Power Planning Council, William Morse from Bonneville Power Administration, and Scott Robinson from Pacific Power for their contributions and support of this analysis. Each has contributed suggestions and critique which have strengthened the analysis and presentation. Responsibility for any errors or omissions, of course, remains with the authors.

Research supported by the Bonneville Power Administration, U.S. Department of Energy, under Contract No. DE-AC-79-83BP11287. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either express or implied, of the U.S. Government.

[1]The possibility exists of a small number of non-electrically heated homes being included in the database, either by large seasonal variation of the baseload or by consumer fuel switching during the time period studied. The electric utility billing record database shows 4,674 homes, or 12 percent of the total 39,068 homes have gas heating equipment. There is no separate code for oil heat. A total of 6,557 billing database homes are coded miscellaneous, 215 are coded as having no heat and there is no code for 2,654 homes. In another database field, 870 homes are coded as having a a gas meter in the service location. A comparison of the homes coded as having gas heat and the homes coded as having gas meters shows 330 homes in both categories. The ambiguity inherent in the utility's heat code system renders database information insufficiently precise for this analysis.

[2]This assumes that the base electric load is 77 percent of the total. End use load profile data results show the mean baseload to be 60 percent fo the total, but the more conservative figure is used here to ensure that legitimate electrically heated households are not excluded.

[3]Source: Bureau of Economic Analysis, Oregon income by county, divided by county population. County population obtained from Portland State University Population Research Center.

[4]Source: Pacific Power & Light Company Weatherization Program Tracking System.

[5]Source: Pacific Power & Light Company Oregon Residential Rate Schedule #4.

[6]Source: Pacific Power & Light Company customer billing records.

[7]Source: State of Oregon Residential Housing Codes.