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An Analysis of the Impact of Residential Retrofits on Indoor Temperature Choice

Terry M. Dinan

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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EXECUTIVE SUMMARY

The purpose of this study is to provide a better understanding of the factors that affect household's choices of indoor temperature levels. Of particular interest, is whether or not households choose higher indoor temperature levels after a weatherization. Such behavior is likely because an increase in the structural efficiency of the home results in a decrease in the cost of a given level of heat. The term "takeback effect" has previously been used to refer to the tendency of households to "take back" some of the potential conservation savings in the form of increased comfort.

In this analysis, a theoretical model, based on household production function theory, is developed to determine what factors might affect household temperature choices. This model is then estimated using monitored indoor temperature data on 252 homes that were weatherized through the Hood River Conservation Project (HRCP). Three alternative econometric models are utilized to sort out the factors that explain variation in average temperature levels <u>among</u> the sample homes and the factors that explain changes in temperature levels <u>within</u> individual households over time.

This analysis reveals that the HRCP residential retrofits resulted in a statistically significant increase in indoor temperature levels. Assuming the average level of increase in efficiency among the sample homes, these results imply a .6°F average increase among the sample homes. Although this level of increase is statistically significant, it is quite small, accounting for only 6.4% of the gap between the predicted and actual savings of the project. The level of takeback observed in low

income households is significantly higher than in mid and high income households. The average level of takeback among low income homes is .9°F, as opposed to the .6°F increase observed in the sample as a whole. Homes that used electricity as their sole heating fuel had significantly lower levels of takeback, averaging .3°F.

In addition to the findings on takeback, this analysis reveals that: marginal electricity prices are significant in explaining changes in household temperature choice over time, and indoor temperature levels tend to be significantly lower in: large homes, low income households, households in the high education category, and households that believe that the main reason to conserve energy is to save money. Further, indoor temperature levels tend to be significantly higher in homes that heat with wood, and in homes whose occupants state that they find it difficult to be comfortable at temperature levels of 68°F or less, ceteris paribus. Finally, this report provides preliminary evidence that outdoor temperature levels had less effect on indoor temperatures following the retrofits than in the pre-retrofit period. This evidence suggests that the retrofits decreased the sensitivity of indoor temperature levels to changes in outdoor temperature levels.

ABSTRACT

The objective of this study is to determine whether or not households choose higher winter indoor temperature levels after their houses have been made more energy efficient. A theoretical model for explaining household temperature choice is developed using a household production function approach. A means model, fixed effects model, and random effects model are used to sort out the observed variation in the pooled cross-section/time-series data set of monitored indoor temperature levels.

This analysis reveals that the HRCP residential retrofits resulted in a statistically significant increase in indoor temperature levels. Assuming the average level of increase in efficiency among the sample homes, these results imply a .6°F average increase among the sample homes. The average level of takeback among low income households is .9°F, as opposed to the .6°F increase observed in the sample as a whole. Homes that used electricity as their sole heating fuel had significantly lower levels of takeback, averaging .3°F.

1. INTRODUCTION

There has been a recent trend in the utility industry towards integrating "conservation energy" resources into the traditional power-supply planning framework (Hirst et al., 1986, p.178). This trend represents a movement toward a more efficient allocation of resources; however, the accomplishment of this objective requires a sound understanding of the factors that affect consumers' energy use decisions. A topic of particular interest is the "takeback effect" associated with efficiency increases, (i.e., Will consumers "take back" the potential energy savings associated with efficiency improvements by increasing their level of comfort?). Increasing indoor temperatures is an important potential source of takeback behavior. Changes in indoor temperature settings will in turn have a substantial impact on household energy use.[1]

This paper utilizes a household production function framework to explore the factors that affect household choice of indoor temperatures. The household production function approach is a particularly useful framework for investigating the issue of takeback because it formally incorporates the role of the household's technology, as well as its tastes, as a determinant of behavior. Therefore, a change in structural efficiency may be viewed as a change in household technology, and its impact on behavior may be assessed.

The magnitude of the effect of changes in structural efficiency on household behavior is determined using an empirical model. This model is

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[1]A reduction in indoor temperature from 70° to 68°F will reduce annual space heating energy use by 10% in locations with 5,000 heating degree days (65°F base) (Hirst et al., 1986, p. 130).

estimated using data from the Hood River Conservation Project (HRCP), a $20 million conservation retrofit project implemented in Hood River, Oregon in 1983-1986. The purpose of the HRCP was to determine the maximum level of conservation that can be obtained from a utility operated residential retrofit program. The issue of takeback is of particular interest in the Hood River project because studies on the actual savings obtained in the retrofitted houses indicate that those savings are less than one-half of the engineering estimates of conservation potential (Hirst, Goeltz, and Trumble, 1987).

This analysis reveals a small but statistically significant level of takeback within the sample as a whole. Low income households are found to have significantly higher levels of takeback than medium and high income households, and households that use only electricity as a heating fuel have significantly lower levels of takeback than households that use wood as a primary or supplemental fuel. In addition, the impact that other factors (e.g. income, education, weather, and attitudes) have on household temperature levels is examined.

2. THE THEORETICAL MODEL

The household production function framework was first developed by Becker (1965) and has since been used to model households' expenditures, consumption, and allocation of time. In this framework, households are viewed as "producing" their desired level of heat. Analysis of indoor temperature levels in a household production function framework is useful in determining: what types of factors might affect indoor temperature choice, the manner in which factors affect temperature choice (i.e., the expected signs of variables in the empirical analysis), and the potential bias created by unobserved factors. This framework reveals the importance of using pooled cross-section/time-series data in examining the effect of efficiency changes on indoor temperature choice, particularly in an area such as the Hood River community, in which many households use wood as a heating fuel. While the development of a theoretical model of temperature choice provides insight into the type of empirical models which should be estimated, readers, who are unfamiliar with or uninterested in household production theory, may choose to jump to Section 3 of this report.

The household production function framework differs from traditional theory in that utility[2] is described as a function of "commodities" rather than market goods. Commodities satisfy needs of the household, such as heat, entertainment, and nutrition. Viewed in this framework, market goods do not yield utility directly but are inputs used in the household's production process. The household may be thought of as a

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[2]Utility may be thought of as satisfaction.

small firm that seeks to "produce" the desired commodities at a minimum cost.

Of particular interest in this study is the household's demand for heat. The process by which the household chooses the level of heat to produce may be formally described in a household production framework by the following model.[3] The household's utility is described as a function of the level of heat, Z_h, and the level of all other commodities that it consumes, Z_o. In addition, it is assumed that the time that the household spends in the production of Z_h and Z_o are a direct source of utility (or disutility)[4]; therefore, the time inputs into Z_h and Z_o (t_1 and t_2 respectively) create two new commodities, Z_1 and Z_2, which appear in the utility function:

$$U = U(Z_h, Z_o, Z_1, Z_2). \tag{1}$$

The household seeks to maximize this utility function subject to its ability to produce Z_h, Z_o, Z_1, and Z_2 as reflected in the production functions (2) - (5) and a budget constraint (6).

$$Z_h = f_h(F, t_1 | W, S, E) \tag{2}$$

$$Z_1 = f_1(t_1) \tag{3}$$

$$Z_o = f_o(x_o, t_2) \tag{4}$$

$$Z_2 = f_2(t_2) \tag{5}$$

$$Y = w(\bar{t} - t_1 - t_2) + A = P_f F + P_o x_o \tag{6}$$

[3]The formal model described here is a modified version of the one used by Deyak and Smith (1978) in describing households' consumption of recreation service flows.

[4]Households that heat with wood may use a significant amount of their own time in the production of heat.

where:

F = fuel,

t_1 = time spent in producing Z_h,

W = weather,

S = house size,

E = efficiency of the house and heating equipment,

x_o = market goods used in producing Z_o,

t_2 = time spent in producing Z_o,

Y = total income,

w = wage rate,

$\bar{t}$ = total amount of time available,

A = assets,

P_f = price of fuel,

P_o = price of market goods, x_o.

Note that the weather, the size of the house, and the efficiency of the house and heating equipment appear as given factors, rather than choice inputs, in the production function for the level of heat (equation 2). Weather is exogenous to the household in the short-run (households may choose weather conditions in the long-run by moving to warmer climates) and is, therefore, not a choice input that the household may control in producing heat. Likewise, the size of the house and the efficiency of the house and heating equipment are variables which are fixed in the short-run. Although these fixed factors of production will affect the cost of obtaining a given level of heat, they are not choice variables that the household has control over in the short-run.

A parallel problem for the household is to minimize the cost of yields a minimum cost function for commodities:

$$C = C(Z_h, Z_o, Z_1, Z_2, P_f, P_o, W, S, E, \bar{t}) \quad (5)$$

The link between the utility maximization process and the cost minimization process occurs when the price of each commodity is defined by its marginal cost (Deyak and Smith, 1978):

$$r_j = \partial C / \partial Z_j \quad (6)$$

where:

r_j = the price of commodity j.

Pollack and Watchter (1975) have questioned the usefulness of the household production function framework in cases in which the commodity production function does not exhibit constant returns to scale or commodities are jointly produced.[5] As a result of joint production or non-constant returns to scale, commodity prices are not parameters to the household but are a function of the quantity of the j^{th} commodity (and/or the joint commodity) that the household chooses to produce. Pollack and Watchter (1975) argue that "if implicit commodity prices depend on the commodity bundle consumed, then the commodity demand relations correspond to those in a model in which consumers are monopsonists or are offered tie-in sales, and there are virtually no substantive results for these cases" (p.258). In this analysis, it is not claimed that the restrictive assumptions of constant returns to scale and no joint production hold.

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[5]Constant returns to scale indicate that a doubling of the input will result in a doubling of the output. Joint production occurs when an input in a production process is also a direct argument in the utility function.

However, it is argued that by making other less restrictive assumptions, the impact of changes in technology or goods prices on commodity demand may be determined.

First, let us begin by examining the implications of non-constant returns to scale. In this case, commodity prices (r_j) will depend on the level of the commodity produced and, as Pollack and Watchter point out, become an endogenous variable (e.g., with decreasing returns to scale, r_j will increase as the amount of commodity j produced increases). Deyak and Smith (1978), however, demonstrate that in the case of non-constant returns to scale, a reduced form model may be used to offer an alternative indirect means of evaluating a household's behavioral response. Illustrating Deyak and Smith's argument in the context of our problem, we may write the demand for heat in time period t as follows:

$$Z_{hit} = \alpha_1 + \alpha_2 Y_{it} + \alpha_3 T_{it} + \alpha_4 r_{hit} + \varepsilon_{it} \tag{7}$$

where:

Y_{it} = full income of household i in time period t,

T_{it} = taste related variables,

r_{hit} = the price of Z_{hi},

ε_{it} = stochastic error.

Since the household "produces" its own heat, the "price" of heat to the household, r_{hit}, is equal to the marginal cost of producing heat. The marginal cost equation is viewed as the household's individual supply equation for heat in time period t:

$$r_{hit} = \beta_1 + \beta_2 Z_{hit} + \beta_3 P_{fit} + \beta_4 S_{it} + \beta_5 E_{it} + \beta_6 W_{it} + \beta_7 w_{it} + \beta_8 Z_{1it} + \tau_{it} \tag{8}$$

where the variables are as previously defined and τ_i represents stochastic error. Note that the price of heat in time period t is a function of the household's chosen level of heat in time period t, Z_{hit}; therefore, constant returns to scale are not assumed in the production of heat. For now, the potential problems presented by the presence of joint production (indicated by the presence of Z_{1it} in the supply equation) will be overlooked and we will assume that Z_{1it} is exogenous.

Equations (7) and (8) may now be solved in terms of the variables outside the household's control, (i.e., the demand for heat in period t, Z_{hit}, and the price of a unit of heat in period t, r_{hit}, may be written as a function of the exogenous variables):

$$Z_{hit} = \frac{\alpha_1 + \alpha_4\beta_1}{1 - \alpha_4\beta_2} + \frac{\alpha_2}{1 - \alpha_4\beta_2} Y_{it} + \frac{\alpha_3}{1 - \alpha_4\beta_2} T_{it} \tag{9}$$

$$+ \frac{\alpha_4\beta_3}{1 - \alpha_4\beta_2} P_{fit} + \frac{\alpha_4\beta_4}{1 - \alpha_4\beta_2} S_{it} + \frac{\alpha_4\beta_5}{1 - \alpha_4\beta_2} E_{it} + \frac{\alpha_4\beta_6}{1 - \alpha_4\beta_2} W_{it}$$

$$+ \frac{\alpha_4\beta_7}{1 - \alpha_4\beta_2} w_{it} + \frac{\alpha_4\beta_8}{1 - \alpha_4\beta_2} Z_{1it} + \mu_{it}$$

$$r_{hit} = \frac{\beta_1 + \beta_2\alpha_1}{1 - \beta_2\alpha_4} + \frac{\beta_2\alpha_2}{1 - \beta_2\alpha_4} Y_{it} + \frac{\beta_2\alpha_3}{1 - \beta_2\alpha_4} T_{it} \tag{10}$$

$$+ \frac{\beta_3}{1 - \beta_2\alpha_4} P_{fit} + \frac{\beta_4}{1 - \beta_2\alpha_4} S_{it} + \frac{\beta_5}{1 - \beta_2\alpha_4} E_{it} + \frac{\beta_6}{1 - \beta_2\alpha_4} W_{it}$$

$$+ \frac{\beta_7}{1 - \beta_2\alpha_4} w_{it} + \frac{\beta_8}{1 - \beta_2\alpha_4} Z_{1it} + \delta_{it}$$

Although it is not possible to estimate the parameters of the demand and supply equations (equations 7 and 8), it is possible to predict behavioral responses to changes in the demand and supply determining factors. Since our interest is in determining the factors that affect household choice of indoor temperature levels, our analysis will consist of estimating the reduced form equation (9). By making reasonable assumptions about the signs of the parameters in the demand and supply equations, the a priori effect of a change in efficiency may be determined. It is assumed that $\beta_2 > 0$ (decreasing returns to scales). It is also assumed that increases in the efficiency of the house reduce the price of heat ($\beta_5 < 0$) and that increases in the price of heat decrease the quantity of heat that is demanded ($\alpha_4 < 0$). Based on the assumptions:

$$\frac{\alpha_4\beta_5}{1 - \alpha_4\beta_2} > 0 \tag{11}$$

Increases in the structural efficiency of the home or the heating equipment are expected to increase the quantity of heat demanded.[6] The actual direction and magnitude of this response, along with the variation in heat level chosen due to changes in the price of heating fuel, weather, income, and taste related variables, will be determined by an empirical model.

Now let us return to the implications of joint production. As previously discussed, households that heat with wood are likely to use

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[6]An exception to this may occur if a household is already at its "bliss point", (i.e., the temperature that it would maintain if it was not subject to a budget constraint). In this case we would not expect α_4 to be less than zero.

their own time in the production of heat (e.g., chopping wood). Since time spent in heat production related activities (t_1) is not neutral but is a source of utility or disutility, this time creates a by-product (Z_{1it}) which appears as an added cost factor in the household's supply equation (equation 8). As Pollack and Watchter (1975) point out, commodity prices now reflect household preferences as well as constraints posed by the household's technology and goods prices. Since the level of utility or disutility associated with time spent in the production of heat (e.g., chopping wood) is likely to be unobservable, this situation may pose significant problems for cross-sectional analysis. Differences in indoor temperature levels that are caused by differences in household tastes (i.e., Z_{1it}) may be wrongly attributed to differences in household technology. It is argued here, however, that this type of joint production does not pose a major problem in examining changes in household behavior over time. If it can be assumed that: (1) Z_1 is consumed only as a by-product of Z_h; (2) Z_{1it} is constant over the time period being considered (two years); and (3) that the per unit level of utility associated with a unit of time spent in heat producing activities is constant (i.e., there are constant returns to scale in the production of Z_1), then Z_{1it} becomes a fixed parameter to the household and changes in household temperatures over time may be viewed as a function of changes in goods prices and the household's technology.

Finally, let us consider other potential sources of joint production. As indicated in equation (8), the price of heat for house i, r_{hit}, is a function of the size of house i. The size of the house is also likely to be a direct argument in the utility function. However, this does not pose a joint production problem since the size of the house is fixed prior to the choice of the indoor temperature setting.[7] Therefore, S_{it}, may be considered as exogenous to the household in the short run. Other activities of the household, such as cooking and entertainment, will affect the cost of achieving a given level of heat since these activities produce heat. However, the amount of heat generated by these activities is assumed to be insignificant and these activities do not appear in the supply equation (8).

The analysis of indoor temperature choice in the context of the household production framework has revealed that there is not sufficient information available to estimate a demand equation for heat. However, by estimating a reduced form equation the behavioral response to changes in tastes, prices, and technology may be determined. The empirical analysis section of this report will explore alternative ways of estimating the appropriate reduced form equation (equation 9). The household production function framework also revealed the importance of using pooled cross-section/time-series data in estimating equation 9 and the expected impact of increases in structural efficiency on indoor temperature levels.

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[7]An exception to this occurs for houses that have zone heating options.

3. THE DATA

The sample used in this study consisted of 252 households in Hood River, Oregon. Monitored indoor temperature data and survey data were available on each household along with weather data from three different weather stations in the Hood River area. These data were available through the Hood River Conservation Project (HRCP), a $20 million, three-year residential retrofit demonstration project. This project was designed to determine the maximum limits of a utility-operated residential retrofit program (Goeltz and Hirst, 1986). Through the HRCP, all households in the town and county of Hood River Oregon that had permanently installed electric space-heating equipment were eligible to receive free home retrofits. A total of 2,989 homes were weatherized through the project, representing a total of 85% of all eligible households (Kaplon and Engels, 1986). A random sample of 319 of the weatherized homes were selected for intensive monitoring in order to determine program induced savings. This analysis utilizes monitored indoor temperature data, survey data, and outdoor weather data on the monitored homes. Due to missing data, 67 of these homes were eliminated from the analysis, leaving observations on 252 households.

Monitored indoor temperature data at the 15 minute level were available on the sample homes for one year prior to the retrofit and one year following the retrofit. Although indoor temperature data were available at a very disaggregate level, only variation in monthly average indoor temperature levels was examined in this analysis. This decision was made because little data were available to <u>explain</u> variation in indoor temperature levels at a less aggregate level of analysis. Outdoor temperature readings at the 15 minute level were also available; however, because of the frequency of missing data, this variable was felt to be more reliable at a monthly average level. No other variables available for the analysis were capable of explaining variation in indoor temperature settings at such a detailed level. While indoor temperature readings were used at a monthly level in the econometric analyses focused on in this report (where the focus was on explaining variation in temperature choice), the availability of less aggregate levels was useful in observing the temporal patterns of temperature levels in the pre- and post-retrofit heating seasons (see Appendix A).

In order to determine the effect of the retrofit on indoor temperature settings, average monthly temperature readings on each household during the months of November, December, January, and February of the pre- and post-retrofit heating season were utilized, providing eight observations on each household's temperature choice. The climate of the Hood River area does not call for significant levels of summer cooling; therefore, the effect of the retrofit on use of air-conditioning was not examined.

The data set provides a particularly good opportunity to estimate the takeback effect since direct observations on indoor temperatures are available. In previous studies, changes in household behavior have been inferred from changes in billing data (see Hirst and White (1985) and Dubin et al. (1986)), and therefore, these studies have relied on less direct observations of takeback. Another desirable aspect of this study is that the customers did not choose the level of efficiency improvement that they would receive. The number of conservation measures that was to the consumer.[8] Since the level of efficiency improvement was exogenous to the consumer, the level of takeback may be determined without concern for the simultaneity of consumer choices of indoor temperature levels and choices of efficiency improvement, (i.e., the impact of the retrofit on indoor temperature choices may be observed without concern for the impact that household preferences for indoor temperature levels had on the level of efficiency increase chosen).[9] A complication resulting from the free installation of measures is that the efficiency improvement may result in a capital gain effect as well as the substitution and income effect that would normally accompany a price decrease. (This issue is more fully discussed in Section 5.)

A very cursory way to begin to explore whether residential retrofits affect households' temperature choices is to examine average indoor temperature levels recorded in the pre- and post-retrofit heating seasons. The results of this type of analysis are presented in Appendix B. The difference between the pre- and post-retrofit average indoor temperature levels is not found to be statistically significant when examined for the sample as a whole. When this difference is examined for the sub-sample of homes that use wood as their primary heating fuel, the post-retrofit average indoor temperature level is found to be

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[8]The program offered a comprehensive package of 15 retrofit measures at very high levels of installation (e.g., R-49 ceiling insulation). Auditors recommended, and HRCP paid for, the installation of these measures up to a cost effectiveness limit of $1.15/first-year estimated kWh saving. Only 10% of the households paid anything for the installed measures and their average payment was $430. The average cost of HRCP-installed retrofit measures was $3,760 (Goeltz and Hirst, 1986).

[9]The previously mentioned study by Dubin et al. (1986) shares this characteristic.

significantly higher than the pre-retrofit heating season average. These findings reveal little about the actual level of takeback, however. Takeback refers to the change in indoor temperature levels brought about by the increase in structural efficiency. Differences in pre- and post-retrofit average indoor temperature levels reflect the impact of changes in other factors that also affect indoor temperature choice (i.e., fuel prices and weather conditions), as well as the impact of changes in efficiency.[10] In order to determine the level of takeback, it is necessary to sort out the individual effects that efficiency and other factors have on household temperature choice. Econometric methods are utilized in this report to determine these individual effects.

Table 1 indicates the names, descriptions, and sources of the variables that were used in this analysis. The dependent variable is the average monthly temperature level for each household during the pre- and post-retrofit heating season (November-February). It should be noted that the monitored indoor temperature level, which is used as the dependent variable in this study, is only a proxy for the level of heat that is chosen by each household in a given period of time. The temperature reading used in this analysis was recorded in the central living area of the house. The actual heat preferences of the household may call for differing temperature levels in the bedrooms, hallways, etc.; however, our measure of heat will not pick up these variations. If households choose to "take back" energy savings after a retrofit by

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[10]It should be noted that the level of takeback brought about by the HRCP may be significant even though the pre- and post-retrofit indoor temperature levels were not significantly different. This is because changes in weather, electricity prices, etc. may have an opposing effect to the change in efficiency.

Table 1. Variables Considered in the Analysis

Variable Name	Description	Source[a]
Dependent Variable		
INTEMP	monthly average monitored indoor temperature levels	1
Independent Variables		
EFFIC	efficiency measure	2
MPRICE	tail rate price of electricity	3
SQFT	square-feet of floor area (1000)	1
OUTTEMP	outdoor temperature	1
COLD*	household located in weather station with the coldest monthly average temperature levels	4
WOOD*	wood used as the primary heating fuel	4
ELEC*	electricity used as sole heating fuel	4
BASE*	homes that use baseboard heating	4
HIGHINC*	income level in highest quarter of sample	4
LOWINC*	income level in lowest quarter of sample	4
HIGHEDUC*	greater than 15 years of school	4
LOWEDUC*	less than 12 years of school	4
HHMEMB	number of members in household	4
CHILD*	child less than 6 years in household	4
SENIOR*	adult greater than 65 years old in household	4
DAY*	indicates household member usually home on weekdays during 9:00 am - 5:00 pm	4
STYLE*	agrees that to reduce energy bills he/she would have to change his/her lifestyle	4
SAVES*	agrees that the main reason to conserve energy is to save money	4
SCARCITY*	believes that scarcity of energy in the state is a serious issue	4
COSTCON*	believe that the cost of energy in the state is a serious issue	4
RIGHT*	does not agree that people have the right to use as much energy as they can afford	4
COMFORT*	agree that in the winter it is difficult to be comfortable if his/her homes temperature is 68^{o}F or less	4

[a]Sources:
1. Hood River project data provided by Pacific Power and Light (PP&L)
2. Constructed for this study, based on Hood River project data
3. Rate information from PP&L and Hood River Co-op (HRCP)
4. On-site home interview conducted by Bardsley and Haslacher in July, 1984.

* Indicates a qualitative variable

maintaining higher temperature levels in the non-central parts of the home, we will not be able to observe this. In addition, having a thermometer reading from only one point in the house may cause households that use certain technologies to appear warmer than others. For example, households that use wood may tend to keep the central living room (where the stove is usually located) of their home substantially warmer than the bedroom areas. Since the temperature level is only recorded in the central living area, wood heated homes may, therefore, appear warmer than electrically heated homes, even though temperatures in parts of the house that are not near the stove may not exhibit this pattern. Similarly, electrically heated homes that use baseboard heaters may appear warmer than homes that use central forced air since baseboard heaters make zoning behavior more effective.

Finally, perceived levels of heat are a function of humidity levels and radiation as well as air temperature. A room with cold walls may feel cold even though the temperature level is high (Scott, 1980, p.132); therefore, the level of heat recorded does not perfectly coincide with the level of comfort experienced by the household. Due to these limitations, the recorded indoor temperature serves only as a proxy for the level of warmth actually chosen by the household.[11]

In order to determine the impact of efficiency changes on temperature choice, it was necessary to define a measure of the efficiency of each house in both the pre- and post-retrofit periods. The

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[11]In addition, it should be noted that monitored indoor temperature levels are only a proxy for thermostat settings. On relatively mild days, indoor temperatures may "float" above the thermostat setting for a period of time providing inflated average temperatures.

pre-retrofit measure of efficiency utilized in this analysis is based on the auditor's estimate of the electricity savings that would result from installing the HRCP measures that were feasible for each home. Specifically, the pre-retrofit measure of efficiency was defined as:

$$EFFICPRE_i = (-1)(SAVE1_i) \quad (12)$$

where:

$EFFICPRE_i$ = the pre-retrofit measure of efficiency for house i,

$SAVE1_i$ = the auditor's estimate of the kWH/sqft savings that could be obtained by installing the HRCP measures that were technically feasible, given the structure of house i and the number of measures already in place.

The post-retrofit level of efficiency is based on the pre-retrofit measure (the auditor's estimate of the home's pre-retrofit conservation potential) minus the predicted savings from the HRCP installed measures:

$$EFFICPST_i = (-1)(SAVE1_i - ACTUALSAV_i) \quad (13)$$

where:

$ACTUALSAV_i$ = the engineering estimate of the kWh/sqft savings that were obtained from the measures that were actually installed during the retrofit.

The efficiency variable, EFFIC, identified in Table 1, takes on the value of EFFICPRE and EFFICPST in the pre- and post-retrofit periods, respectively. The pre- and post-retrofit efficiency measure for each house is based on its remaining conservation potential. Unfortunately, the remaining conservation potential reflects not only the current level of efficiency of the home but also relevant structural barriers. Therefore, according to the efficiency measure used, a home that had structural barriers which prevented installation of some HRCP measures would appear more efficient in the pre-retrofit period than an otherwise identical house that had no structural barriers. Although this creates a problem for cross-sectional comparisons of structural efficiency at a given point in time, the efficiency measure used is thought to be accurate in portraying the relative increases in efficiency in sample homes. The implications of the strengths and weaknesses of the efficiency measure used will be further explored in the following sections of this report.

As previously stated, eight observations (i.e., four monthly temperature levels in both the pre- and post-retrofit heating seasons) on each of the 252 households' indoor temperature level were used in this analysis. Therefore, the data set represents a pooled time-series and cross-sectional data set (also referred to as a panel data set). The challenge in using panel data is to specify a model that will adequately allow for differences in behavior among cross-sectional units and over time for a given cross-sectional unit. In this study, three alternative models are used to provide insight into the factors that affect household temperature choice. A "means model" is used to analyze differences in the average temperature settings among households. A "fixed effects" model is used to analyze changes in household settings over time, and a "random effects" model is used to simultaneously examine differences among households and differences within households over time. The random effects model may be viewed as an efficient combination of the means and fixed effects model. Each of these models will be presented in the following section.

4. THE EMPIRICAL ANALYSIS

4.1 THE MEANS MODEL

The means model examines variation in average temperature levels among sample homes. The model may be described as follows:

$$\bar{Y}_i = \beta_1 + \sum_{k=2}^{K} \beta_k \bar{X}_{ki} + e_i \qquad (14)$$

where:

$\bar{Y}_i$ = average indoor temperature level for household i over the pre- and post-retrofit heating season months,

$\bar{X}_{ki}$ = average level of explanatory variable k for household i over the pre- and post-heating season months,

e_i = error term for household i.

Since household averages are used for both the dependent and independent variables, the means model only examines differences in average temperature levels among sample homes without examining differences in individual household's temperature levels over time. The results of the means model are indicated in Table 2.

The means model reveals some interesting insights into the variation among households' average temperature levels. As indicated in Table 2, this analysis shows that households in the low income category, LOWINC, (households with incomes in the lowest 4^{th} of the sample) maintained significantly lower average temperature levels than the rest of the sample, ceteris paribus. It is likely that these households are less able to afford the luxury of warmer indoor temperature levels. Households in the high income category, however, were not found to have significantly different indoor temperature levels than households in the

Table 2. Results from the Means Model

Variable	Coefficient	t-value
Intercept	75.61	34.88***
Average MPRICE[a]	-43.16	-1.28
Average EFFIC	0.13	1.00
COLD	-0.92	-1.36
SQFT[b]	-0.002	-4.25***
BASE	0.84	1.85*
WOOD	2.47	4.64***
ELEC	-0.43	-0.70
LOWINC	-2.13	-3.77***
HIGHEDUC	-1.73	-3.01***
DAY	1.53	3.05***
SAVES	-1.45	-2.51**
COMFORT	1.66	3.50***

$R^2 = 0.30$
Adjusted $R^2 = 0.26$
[a] in dollars
[b] in thousands

* Significant at a 90% confidence level
** Significant at a 95% confidence level
*** Significant at a 99% confidence level

mid income category.[12] These results may imply the presence of a threshold effect of income on temperature settings. Households below a certain income level will choose lower indoor temperature levels; however, above this, threshold level changes in income will not affect indoor temperature choice.

The negative coefficient on HIGHEDUC (see Table 2) indicates that households in the high education category maintained significantly lower average temperature levels than other homes, ceteris paribus. Households in the mid and low education categories were not found to have significantly different indoor temperature levels from each other, however. These results may indicate that higher educational levels are correlated with an unobserved conservation ethic, or perhaps increased education increases the awareness of the savings induced by lower indoor temperature settings.

It is interesting to note the impact of the two attitude variables that were included in the analysis. Households that indicated that they found it difficult to be comfortable at temperature levels of less than 68°F (indicated by the variable COMFORT), were found to have significantly warmer homes than other households, ceteris paribus. Households that agreed that the main reason to conserve energy is to save money (indicated by the variable SAVES) were found to have significantly lower temperature levels than households that did not agree with this statement. Other attitudes, such as concern for the scarcity of energy in the state and beliefs about the right of people to consume as much

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[12]This result was obtained by including the variable HIGHINC into the analysis. This variable was not significant and was, therefore, omitted from the analysis.

energy as they can afford were not found to be significant in explaining variation in average temperature settings and were, therefore, not included in the final model presented here. (See Table 1 for a description of the attitude variables that were explored in this analysis.) It is interesting to note that these results are consistent with the findings of other researchers that have examined the link between attitudes and conservation behavior. In a review of such studies, Olsen (1981) concluded that broad attitudes about the seriousness of the energy crisis bear little relationship to energy saving practices. However, energy saving practices were found to be correlated with the extent to which individuals perceived energy conservation as having direct personal consequences on themselves (p. 118).

As one would expect, households in which someone was usually home during the day (indicated by the variable DAY) were found to have significantly higher average temperature levels than households in which no one was home during the daytime hours. In addition, large homes were found to have significantly lower indoor temperature levels than small homes (indicated by the negative coefficient on SIZE). This result is consistent with the a priori expectations formulated from the household production function framework. As the size of the house increases, the cost of maintaining a given temperature level increases, this in turn is expected to result in a decrease in the level of heat demanded.

It should also be noted that households that use wood as their main source of heating fuel (WOOD=1) were found to be significantly warmer than other sample homes, ceteris paribus. This result could indicate that the price of heating with wood is less than the price of heating with electricity and, therefore, wood heating households choose higher temperature levels. Recall from the theoretical section of this paper that the price of heat derived from wood depends not only on the price of wood but on the opportunity cost of the households' time (since time is an input into the production function for heat in wood heated homes) and the amount of satisfaction or dissatisfaction that households obtain from the heat producing activities (e.g., chopping wood). Since no observations on these cost determining factors were available, one must be cautious in attributing the positive coefficient on the wood variable to a price effect. As pointed out above, the limitations of our indoor temperature observations are likely to make wood heated households appear warmer than electric heated households. If the wood stove is in the part of the house where the thermometer is located, then wood heated homes may appear significantly warmer than electric heated homes even though this pattern is not consistent throughout the entire home.

The results of the means model do not indicate that differences in average building efficiency levels explain differences in average indoor temperature levels. However, one must be extremely cautious in interpreting the coefficient on the efficiency variable in the means model. As pointed out in the theoretical section, the lack of observations on the cost determining factors for wood produced heat (e.g. households' preferences for chopping wood) could create a bias in the efficiency coefficient in the means model. This is particularly likely if there is a correlation between households' preferences for the activities involved in using wood for heat and the efficiency of their home. Also, as pointed out above, the efficiency measure available for use in this study is more accurate in revealing changes in efficiency levels over time for each of the sample homes than it is in revealing differences in efficiency levels among the sample homes. Therefore, although the means model reveals interesting insights into some of the factors that explain variation in average indoor temperature levels among sample homes, it is not the preferred model for examining the impact of changes in efficiency on temperature choice. The fixed effects model (discussed below) is a much more accurate model for determining this effect.

4.2 THE FIXED EFFECTS MODEL

The fixed effects model examines differences in household temperature levels over time, without examining the factors that may explain differences in average temperature levels among sample homes. In a fixed effects model, each household is modeled as having a separate, fixed, intercept term. This model may be described as follows:

$$Y_{it} = \beta_{1i} + \sum_{k=2}^{K} \beta_k X_{kit} + e_{it} \tag{15}$$

where:

Y_{it} = average indoor temperature for household i in time period t (t = Nov., Dec., Jan., and Feb., of both the pre- and the post-retrofit heating season),

X_{kit} = value of k^{th} independent variable for household i in time period t.

e_{it} = error term for household i in time period t.

Each household specific intercept term, β_{1i}, is a fixed parameter. One method for estimating this model is to utilize a separate dummy variable for each household to reflect the household specific intercepts. However, when the number of households is large (as in this case) a more feasible method for estimating a fixed effects model is to transform the dependent and independent variables by expressing them as deviations from their means for the i^{th} individual:

$$Y^*_{it} = \sum_{k=2}^{K} \beta_k X^*_{kit} + e^*_{it} \qquad (16)$$

where:

$$Y^*_{it} = Y_{it} - \bar{Y}_i \quad ,$$

$$X^*_{kit} = X_{kit} - \bar{X}_{ki} \; ,$$

$$e^*_{it} = e_{it} - \bar{e}_i \quad .$$

The results obtained from estimating equation 15 are shown in Table 3. Note that in the fixed effects model, all of the factors that are constant for a household over time (e.g., income, education, attitudes) drop out of the analysis since they are equal to their mean levels (i.e., for these variables $X_{kit} - \bar{X}_{ki} = 0$). Since a fixed effects model examines variation in observed household temperature levels around the average household temperature as a function of variation in the independent variables around their household specific means, the coefficients of the fixed effects model provide information on <u>within</u> household effects. Only three of the explanatory variables that were available for this analysis (see Table 1) are assumed to change over the study period (November 1984 - February 1986). These three factors are:

Table 3. Results from the Fixed Effects Model

Variable	Coefficient	t-value
MPRICE[a]	-545.38	-2.34**
EFFIC	0.12	6.25***
OUTTEMP	0.01	1.20

R^2 = 0.0199
Adjusted R^2 = 0.0184
[a] in dollars

* Significant at a 90% confidence level
** Significant at a 95% confidence level
*** Significant at a 99% confidence level

the marginal price of electricity, outdoor temperature levels, and the level of efficiency of the home. The remaining independent variables (e.g., household income, education, attitudes) are assumed to be constant over the study period. This assumption is necessary because data on these factors were collected only during the pre-retrofit time period. Although these factors are thought to be relatively stable for households during a limited time period, any systematic changes that might have occurred in these variables may result in bias in the fixed effects model coefficients.

Prior to discussing the results of the fixed effects model, it should be noted that this model explains only two percent of the observed variation in monthly average indoor temperature levels (indicated by the value of the R^2 statistic). This result is not altogether surprising when the construction of the model is considered. Although eight observations on each household's indoor temperature level are included as dependent variables (four monthly averages in the pre-retrofit heating season and four monthly averages in the post-retrofit heating season), only one of the independent variables changes with each of these eight observations. The outdoor temperature level, OUTTEMP, varies in each of the eight months included in the analysis; however, the marginal price of electricity, MPRICE, and the efficiency of the house, EFFIC, change only between the heating seasons. It is not surprising, therefore, to find a large amount of unexplained variation in the dependent variable. Although the model explains only 2% of the variation in indoor temperature levels, this does not invalidate the model results for the included variables (see Kmenta, 1971, p. 234).

As indicated in Table 3, the marginal price of electricity was found to be significant in explaining changes in monitored indoor temperature levels over time.[13] The sample homes lie in two different utility areas. The Hood River Co-op (HREC) serves 41% of the homes in the sample while Pacific Power and Light (PP&L) serves the remaining 59% of the sample homes. The rate structures of the two utilities are different. HREC had a fixed charge of $8.00 per month and a single rate of $.0359/kWh throughout the entire study period. PP&L had a fixed charge of $3.00 per month and three separate rates during the pre-retrofit heating season. All customers paid $.03303/kWh for the first 300 kWh consumed each month, $0.04866 for the next 700 kWh consumed, and $.05179/kWh for all kWh past the first 1000. Households in PP&L experienced a change in the rate structure and an increase in the nominal tail rate of electricity during the sample period. In the post-retrofit period PP&L customers paid $.04237/kWh for the first 300 kWh consumed each month and $.05241 for each kWh past the first 300. Therefore, the nominal tail rate of electricity for PP&L customers increased from $.05179 to $.05241 between the pre- and post-retrofit heating seasons, while the tail rate remained constant at $.0359 for HREC customers. The baseload of electricity is sufficiently high for sample homes that the tail rate may be used as the

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[13]Note that marginal electricity prices were not significant in the means model (Table 2). In the means model, the marginal electricity price used for each household is the average tail rate of electricity paid by that household over the entire study period. Therefore, no temporal changes in electricity prices are reflected in the means model. The only variation in marginal electricity prices incorporated into the means model is due to differences in utility areas. The electricity price coefficient in the means model, therefore, is likely to be highly correlated with other factors that might differ between the two utility areas and is a poor indicator of electricity price effects.

relevant marginal price of electricity that is used for space heating.

The results from the fixed effects model indicate that nominal marginal electricity prices have a significant effect on indoor temperature levels. The coefficient obtained on the marginal price variable in the fixed effects model implies that the effect of the increase in the marginal price of electricity from $.05179 to $.05241 for PP&L households resulted in an average decrease in indoor temperature levels of .34°F. There is a need for caution in drawing this conclusion, however. There is very little variation in marginal electricity prices over the study period. HREC prices remained constant while the PP&L tail rate increased by one-sixth of a cent. In order to draw sound conclusions about the effect of changes in the nominal price of electricity on indoor temperature levels, it is desirable to have more observations on indoor temperature levels under alternative prices. In this analysis, a systematic change in an unobserved variable could be correlated with the nominal price change for PP&L customers. For example, an unobserved change in attitudes of PP&L customers over the study period would be correlated with the observed change in prices.[14] Such correlation would bias the coefficient on the marginal price variable.

A relevant question, of course, is whether households are more likely to respond to changes in the real price of electricity as opposed

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[14]Note that the danger of correlation between unobserved changes in attitudes and changes in efficiency are minimized because of the variation in the efficiency increases observed among homes. Although the efficiency levels of all houses increased over the sample period, the magnitude of this increase varied among homes, therefore, it is unlikely that changes in unobserved attitudes would be closely correlated with observed changes in efficiency.

to changes in nominal prices.[15] The real marginal price of electricity was lower in the post-retrofit period for homes in both HREC and PP&L. (This result occurs because the PP&L rate increase was less than the inflation rate). When real prices are used in the fixed effects model, the coefficient obtained on the marginal price variable is positive. A positive coefficient on the price variable is counter-intuitive, since increases in prices are expected to result in decreases in indoor temperature levels. This result indicates that the sample households appear to have responded to changes in nominal electricity prices, rather than changes in real prices. As pointed out above, however, a great deal of caution should be used in drawing conclusions about price effects in this analysis since there is little variation in electricity prices (in either real or nominal terms) over the sample period.

As indicated in Table 3, the outdoor temperature variable is not significant in explaining variation in indoor temperature levels. In order to further understand the relationship between indoor and outdoor temperature levels, the fixed effects model was re-estimated for the pre- and post-retrofit periods individually. (In these re-estimated models, OUTTEMP was the only independent variable because the marginal price of electricity and the efficiency level of the house were constant within a given heating season). This experiment revealed that outdoor temperature levels were significant in explaining variation in indoor temperature levels in the pre-retrofit heating season[16] but not in the post-retrofit

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[15]Real prices are prices that have been adjusted to net out inflation. Increases in nominal prices reflect both inflation and increases in real prices.

[16]This relationship was found to hold at a 90% confidence level.

heating season. In the pre-retrofit heating season, higher outdoor temperature levels resulted in higher indoor temperature levels; however, outdoor temperature levels did not significantly affect indoor temperature levels in the post-retrofit heating season. These results indicate that the retrofits significantly decreased the sensitivity of indoor temperature levels to changes in outdoor temperature levels. In order to explore the relationship between indoor and outdoor temperature levels more fully, daily average indoor temperature levels were regressed against daily average outdoor temperature levels. The results of this analysis are presented in Appendix C.

As indicated in Table 3, changes in efficiency were found to have a significant impact on indoor temperature levels. A one unit increase in efficiency is expected to increase the monthly average indoor temperature level by .12°F. Using information on the average increase in efficiency in the sample homes, this result implies an average increase of .56°F among the sample homes.[17] The level of "takeback" (i.e., the increase in indoor temperature level caused by an increase in structural efficiency) observed in this analysis is small, yet statistically significant. The variation in takeback among households in different income classes and which use different fuel types will be further explored in the random effects model described below.

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[17]Recall that the measure of efficiency utilized in this analysis was based on the remaining conservation potential for each household on a per square foot basis. The average decrease in remaining conservation potential in the sample homes was 4.81 kWh/sqft, therefore, (.12)(4.81) = .56°F.

4.3 THE RANDOM EFFECTS MODEL

A random effects model simultaneously examines factors that explain differences in temperature levels among households and within households over time. The random effects model is similar to the fixed effects model in that a separate intercept term is fitted for each household. Unlike the fixed effects model, however, this intercept term is assumed to be a function of a fixed constant and a random variable. A random effects model may be described as follows:

$$Y_{it} = \beta_{1i} + \sum_{k=2}^{K} \beta_k X_{kit} + e_{it} \tag{17}$$

where:

$\beta_{1i} = \bar{\beta}_1 + \mu_i$

$\bar{\beta}_1$ = a fixed constant

μ_i = a random variable

A key assumption in estimating a random effects model is that the random component of the household specific intercept term, μ_i, is uncorrelated with the explanatory variables. If this assumption does not hold, then the coefficients obtained in the random effects model will be biased.[18] If this assumption holds, then there are two advantages to be obtained from estimating a random effects model. First, a random effects model is able to simultaneously examine the factors that explain both among and within household variation. Second, the parameter estimates obtained from the random effects model are more efficient than those obtained from the fixed effects model. The assumption that the random

[18]If this assumption does not hold it is similar to an omitted variable problem, in which correlation between the omitted variable and the explanatory variable results in biased coefficients.

component of the household specific intercept term is uncorrelated with the explanatory variables was tested using a specification test developed by Hausman (1978).[19] The results of the Hausman specification tested indicated that this assumption holds.

In order to estimate a random effects model using a standard regression procedure, it is necessary to transform the dependent and independent variables. The transformation used is:

$$Y_{it} - \Theta\overline{Y}_i = (1 - \Theta)\overline{\beta}_1 + \sum_{k=2}^{K} \beta_k(X_{kit} - \Theta\overline{X}_{ki}) + \varepsilon_{it} \qquad (18)$$

where:

$$\Theta = 1 - \frac{\sigma_\varepsilon}{\sigma_1}$$

σ_ε = the square root of the corrected mean square error from the fixed effects model

σ_1 = the square root of T times the mean-square error from the means model (T=the number of observations on each household=8).

The transformation consists of subtracting a weighted household mean of the value of the dependent and independent variables from their observed values in time t. The weight, Θ, is a function of the residual variance from the means model and the fixed effects model. Due to the fact that the model is constructed in this way, the coefficients from the random effects model are a matrix weighted average of the coefficients obtained from the means model and fixed effects model.

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[19]This specification test rests on the fact that if the assumption holds, then the coefficients obtained in the random effects model should be within sampling error of the coefficients obtained in the fixed effects model. An expanded regression framework is utilized to test whether this result holds.

The results of the random effects model are presented in Table 4. Prior to discussing the model results, it should be noted that a Lagrange Multiplier test revealed the presence of heteroskedasticity in the residuals resulting from the random effects model.[20] White (1980) demonstrated that consistent covariances may be estimated in the presence of heteroskedasticity without specifying a formal model of the structure of the heteroskedasticity. Using the ACOV option in SAS (1985), these consistent covariance estimates may be obtained. All of the t-values indicated in Table 4 are calculated using the standard errors resulting from the consistent covariance estimates.

As with the fixed effects model, the R^2 statistic for the random effects model is very low. The R^2 value indicates that the model explains approximately 6% of the variation in observed indoor temperature levels. Since eight observations on monthly average temperature levels are used in this analysis, a large amount of the variation in the dependent variable is due to changes in household temperature levels over time. However, as previously mentioned, only three of the explanatory variables in the model change over time for a given household - outdoor weather conditions, electricity prices, and structural efficiency. The remaining variables explain only the variation in the dependent variable which is due to differences in average temperature levels <u>among</u> households, not to <u>within</u> household variation. As discussed in section

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[20]The Lagrange Multiplier test for heteroskedasticity consists of regressing the squared residuals on the independent variables. The test statistic, TR^2, (where T is the number of observations) will have a limiting chi-square distribution with k degrees of freedom under the null hypothesis of homoskedastic variances (see Griliches (1984) p. 803).

Table 4. Results from Random Effects Model

Variable	Coefficient	t-value[a]
Intercept	22.634	8.84***
MPRICE[b]	-571.263	-2.55**
OUTTEMP	0.013	1.18
SQFT[c]	-0.002	-4.61***
EFFIC	0.126	4.41***
EFFIC*LOWINC	0.092	2.36**
EFFIC*ELEC	-0.095	-2.49**
LOWINC	-1.859	-3.30***
ELEC	-0.638	-0.93
WOOD	2.433	4.34***
BASE	0.901	2.01**
HIGHEDUC	-1.864	-3.02***
COMFORT	1.684	3.44***
SAVES	-1.475	-2.09**
DAY	1.494	2.46**
HRIVER	-9.001	-2.52**

R^2 = .0681
Adjusted R^2 = .0612
[a] t-values computed using White standard errors
[b] in dollars
[c] in thousands

* Significant at a 90% confidence level
** Significant at a 95% confidence level
*** Significant at a 99% confidence level

4.2, a low R^2 does not invalidate the model results for the included variables.[21]

The coefficients on the variables in the random effects model are very close to those obtained in the means model and in the fixed effects model. In summary, the random effects model reveals that: marginal electricity prices and the efficiency of the house are significant in explaining changes in household temperature choice over time; indoor temperature levels tend to be significantly <u>lower</u> in: large homes, low income households, households in the high education category, and households that believe that the main reason to conserve energy is to save money; finally, indoor temperature levels tend to be significantly <u>higher</u> in homes that heat with wood, and in homes that state that they find it difficult to be comfortable at temperature levels of 68°F or less, ceteris paribus.

The interaction terms which were included in the random effects model (i.e., EFFIC*LOWINC and EFFIC*ELEC) reveal interesting insights into the variation in takeback behavior among different types of households. The change in indoor temperature brought about by a one unit change in the level of efficiency is significantly higher in low income households, ceteris paribus, and significantly lower in homes that heat with only electricity. The change in indoor temperature brought about by a one unit change in efficiency is indicated by the partial derivative of the random effects model equation with respect to efficiency:

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[21]In a previous study of takeback by Dubin et al (1986), similar R^2 values were obtained (R^2 = .072 and R^2 = .051). The dependent variable in that study was the ratio of actual kWh usage to projected kWh usage (using monthly household data).

$$\frac{\partial TEMP}{\partial EFFIC} = .126 + .092\ (\overline{LOWINC}) - .095\ (\overline{ELEC}) = .122 \qquad (19)$$

Assuming the average level of efficiency improvement, these results indicate that the average level of takeback is .6°F for the sample as a whole. The average takeback for low income households is .9°F and the average takeback for electrically heated homes is .3°F.

While the results of the random effects model provide useful information on the level of takeback which occurred among retrofitted homes and on how the level of takeback varied among different fuel types and income groups, they do not provide any information on when during the day temperature levels were higher. Insight into this issue is provided by Stovall and Fuller (1987). They compared daily temperature profiles for a subsample of the HRCP monitored homes during the pre- and post-retrofit periods. The results of their analysis indicate that takeback may be most likely to occur in the nighttime hours (see Appendix A).

The fact that homes that use electricity as their sole heating fuel have significantly lower levels of takeback than homes that use wood as either a primary or supplemental fuel may be due to the nature of the technologies used in wood and electric heat. In electrically heated homes the indoor temperature level is normally determined by adjusting a thermostat. In wood heated homes, the temperature level is determined by adjusting the amount of wood that is burned. It is possible that households that heat with wood may have some unintended levels of takeback because it is more difficult for them to re-adjust their wood using habits to adapt to the new level of structural efficiency, leading to overheating.

The finding that takeback levels are significantly higher in low income households is not surprising from an economic point of view. Since heating costs are likely to constitute a larger share of the household budget in low income households, the magnitude of the income effect[1] caused by the decrease in the price of heat will be greater for low income households. In addition, since low income households were found to have significantly lower indoor temperature levels than mid or high income households (as indicated in both the means model and the random effects model), they are more likely to have pre-retrofit temperature levels that are below their optimal comfort level. Therefore, they will have more motivation to choose higher temperature levels as the cost of heat is reduced.

Because low income households had higher levels of takeback than mid and high income households, the difference in observed temperature levels between low income households and non-low income households decreased over the sample period. The impact of membership in the low income category on observed indoor temperature levels is obtained from the partial derivative of the random effects model equation with respect to LOWINC:

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[1]As the price of a commodity, say commodity "X", decreases, the household has more income to spend. The household may use some of this additional income to consume more of commodity X (as well as consuming more of other goods as well). This effect is referred to as an "income effect". In addition to the income effect, the decrease in the price of commodity X results in a substitution effect. The substitution effect refers to the increase in consumption of commodity X which occurs because the relative price of commodity X (relative to other commodities) has declined.

$$\frac{\partial TEMP}{\partial LOWINC} = -1.859 + .092\ (\overline{EFFIC}) = -2.10 \qquad (20)$$

Assuming the average pre- and post-retrofit efficiency levels, these results imply that during the pre-retrofit period, low income households had indoor temperature levels that were 2.4°F lower than mid and high income households, ceteris paribus. During the post-retrofit period, however, this gap was reduced to 1.9°F.

5. IMPLICATIONS OF MODEL RESULTS

The average takeback of .6°F per household indicates that the behavioral changes by households, due to the decrease in the price of heat which resulted from the retrofit, decreased the program induced savings by an amount of 225 kWh/household (Hirst, Goeltz, and Trumble, 1986). The actual level of savings per household were found to be approximately 2,600 kWh, as opposed to the 6,100 kWh which were predicted by engineering based estimates (Hirst, Goeltz, and Trumble, 1986). The increase in indoor temperature levels brought about by the retrofits, therefore, account for 6.4% of the gap between the predicted and actual savings. If the engineering estimates of programmatic savings were to be adjusted to reflect the observed level of takeback, they would have to be reduced by 3.7%.

A relevant question, of course, is: Can inferences about the level of takeback that will be associated with other programs be drawn from the level of takeback found in this study? This is always a difficult issue to address; however, several issues should be kept in mind when inferring from these results.

First, since the households in the HRCP received the retrofits for free, they received a windfall capital gain due to their participation in the retrofit program (recall that the average value of the retrofit was $3,760). This capital gain may have created an added incentive to "takeback" conservation savings in the form of increased comfort, (i.e., since the actual level of wealth of the household has increased due to the program, this additional wealth may result in increased consumption of heat). The capital gain effect is similar to an income effect.

Unfortunately, it is not possible to determine what proportion of the takeback effect, which is observed in this study, is due to the capital gain impact as opposed to the substitution and income effect that are brought about by the reduction in the price of heat (see footnote 17 for an explanation of the income and substitution effects).

Second, takeback behavior is expected only if the pre-retrofit indoor temperature levels are less than the "bliss point" temperature, (i.e., the temperature level which households would maintain if heat was free). In the Hood River area, the pre-retrofit average indoor temperature level was 71.4°F. In communities in which the pre-retrofit temperature levels are substantially lower or higher, we might expect the level of takeback to be higher or lower, respectively.[23]

Third, it should be noted that the level of takeback which occurred was significantly higher in low income households and significantly lower in houses that used electricity as their sole heating fuel (as opposed to houses that used wood as either a primary of supplementary fuel source). Therefore, we might expect that programs that are directed at low income households would find higher average levels of takeback than the .6°F sample average found in this analysis. Likewise, programs in communities in which wood is not used as a heating fuel might expect lower levels of takeback, ceteris paribus.

Fourth, the cost of electricity in the Hood River area is low relative to the national average.[24] Takeback levels may be higher in

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[23]It is possible, however, that the "bliss point" will vary among different regions of the country.

[24]The average cost of residential electricity in the U.S. in 1985 was $.0779/kWh (EIA, 1986).

areas in which the cost of electricity is higher because the value of conserved electricity is greater in these regions.

Finally, it should be noted that we have only been able to observe the level of takeback in the first year following the retrofits. Ideally, we would like to observe takeback behavior over a period of years to determine whether or not it is constant. It is possible that households need time to learn how much the cost of heat has been reduced by the increase in structural efficiency, and to adjust their behavior accordingly. Households may increase their takeback behavior over time as they realize that the cost of a given level of heat has been reduced. Conversely, if households learn over time that the retrofit has not reduced the cost of heat by the amount that they expected, they may tend to decrease their takeback behavior over time.

6. COMPARISON WITH PREVIOUS STUDIES OF TAKEBACK

A review of the literature revealed two previous studies in which the impact of energy efficiency on heat consumption was examined. As previously discussed, both of these studies utilized billing data, rather than observed temperature data, to estimate levels of takeback.

Hirst and White (1985) estimated the level of takeback in homes that had received financial assistance for residential retrofits from the Bonneville Power Administration (Bonneville). Two groups of program participants were examined, those that participated in 1982 and those that participated in 1983. For each of the two groups, changes in indoor temperature levels were estimated from changes in electricity bills, and these changes were then compared with the indoor temperature changes that were estimated for a control group of nonparticipants over the same time period. Based on the results of this analysis, the authors estimate that the level of takeback was .4°F for 1982 participants and 1.0°F for 1983 participants.

Given that the extent of the retrofits in the financial assistance program was significantly less than the retrofits performed in the HRCP (the average cost of the retrofits in this program was $1,700 as opposed to $3,760 in the HRCP), it would be expected that the level of takeback found for these program participants would be less than the level found among HRCP participants. The level of takeback found among the 1982 participants in the Bonneville program is less than the average level of takeback found among the HRCP participants (.6°F); however, the level of takeback found among the 1983 participants is greater than .6°F. In comparing the results of the Hirst and White study with the results obtained in this analysis, it is important to note that Hirst and White point out the need for caution in analyzing their results. Such caution is necessary because of the lack of direct observations of temperature levels and the strong assumptions that were made in imputing indoor temperature changes from changes in electricity use. While they attach importance to the qualitative results of their analysis--that households, on average, slightly increase temperature settings after retrofit--they express doubt concerning the accuracy of the actual levels of takeback which they obtain (p.33).

Dubin et al. (1986) examined the impact of efficiency improvements on households' heat consumption for 214 homes that participated in a conservation program implemented by Florida Power and Light. Through this program each participating household received one of three efficiency improvements: (1) upgraded attic insulation, (2) upgraded attic insulation and a high-efficiency heat pump with conventional electric furnaces, or (3) upgraded insulation and a high-efficiency heat pump. As in the HRCP program, these efficiency improvements were provided free of charge to the program participants. In order to approximate changes in indoor temperature levels from electricity consumption data, Dubin et al. estimated the non-heating component of total electricity use and subtracted this from total electricity use. The remaining estimate of actual heating consumption was then compared to a projected level of consumption obtained from a thermal load model. The ratio between actual and projected heat consumption level for each household was modeled as a function of the "price of heat" (which reflects both electricity prices and efficiency levels), household income, and the number of household members.

The authors find that the price of heat has a significant effect on the level of heat that is consumed. Based on their results, they estimate that actual conservation is 8-12% below the engineering estimates due to the increase in heating consumption brought about by the increase in efficiency. The results of our analysis reveal that it would be necessary to adjust the engineering estimates of HRCP savings downward by 3.7% in order to reflect the impact of efficiency on indoor temperature choice. It is difficult to compare the magnitude of Dubin et al.'s results with the magnitude of the results in this study, however, because it is not known how the level of increase in energy efficiency compares in the two studies. In addition, the coefficient obtained on the efficiency variable in this study, EFFIC, is not directly comparable with the coefficient on the price of heat in Dubin et al.'s study because efficiency reflects only one component in the price of heat.

7. SUMMARY

In this study, household indoor temperature choices have been examined in the context of a household production function framework. A reduced form equation was developed to describe the manner in which cost and demand determining characteristics might affect winter indoor temperature levels. This equation was estimated using monitored indoor temperature data on 252 homes that were retrofitted through the Hood River Conservation Project. A means model, fixed effects model, and random effects model were utilized to sort out the factors which explain variation in average temperature levels among households and the factors which explain changes in household temperature levels over time.

This analysis revealed that the HRCP residential retrofits resulted in statistically significant increases in indoor temperature levels. Assuming the average level of increase in efficiency among the sample homes, these results imply a .6°F average increase among the sample homes.[25] Although this level of increase is statistically significant, it is quite small, accounting for only 6.4% of the gap between the predicted and actual savings of the project. The level of takeback observed in low income households is significantly higher than in mid and high income households. The average level of takeback among low income homes is .9°F, as opposed to the .6°F increase observed in the sample as

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[25]Note that this result holds even though the average pre- and post-retrofit indoor temperature levels were not significantly different from each other as shown in Appendix A. Weather and electricity prices, or other unobserved factors, may have opposing effects in indoor temperature levels, causing the pre- and post-retrofit temperatures to not be significantly different even though the level of takeback is significant.

a whole. Homes that used electricity as their sole heating fuel had significantly lower levels of takeback, averaging .3°F.

In addition to the findings on takeback, this analysis revealed that: marginal electricity prices are significant in explaining changes in household temperature choice over time; indoor temperature levels tend to be significantly lower in: large homes, low income households, households in the high education category, and households that believe that the main reason to conserve energy is to save money; finally, indoor temperature levels tend to be significantly higher in homes that heat with wood, and in homes that state that they find it difficult to be comfortable at temperature levels of 68°F or less, ceteris paribus.

A great deal of caution must be used in inferring from these results to other conservation programs. The level of takeback associated with other conservation programs may vary depending on: the initial indoor temperature levels in the retrofitted homes; the proportion of low income homes in the program; and the amount of wood use in the retrofitted homes. In addition, it is pointed out that the level of takeback may not be constant over time. Ideally, future studies would observe household temperature levels for several years following a retrofit.

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APPENDIX A

COMPARISON OF PRE- AND POST- RETROFIT INDOOR TEMPERATURE PROFILES

Stovall and Fuller (1987) compared profiles of indoor temperature levels for households during the pre- and post-retrofit periods. This analysis was completed for the subsample of the HRCP monitored homes that used electricity as a primary heating fuel. The comparison of average hourly temperature levels was based on about 40 "similar" days in the pre- and post-retrofit periods. Days were defined to be similar if their average and minimum temperatures matched within 5°F and if their day of the week was the same. The results of this analysis are shown in Figure A.1.

As indicated in Figure A.1, the observed difference in temperature levels in the pre- and post-retrofit periods is the greatest between the hours of 5:00 and 6:00 a.m. This difference is the least between the hours of 5:00 and 6:00 p.m. The results of the work by Stovall and Fuller suggest that the levels of takeback found in the fixed effects and random effects models (Section 4.2 and 4.3) may reflect increases in night time temperatures rather than increases in daily temperature levels. Re-estimation of the fixed and random effects models using average nighttime and daytime settings (e.g., 5:00 a.m. and 5:00 p.m.) as the dependent variable might provide further insight into this issue.

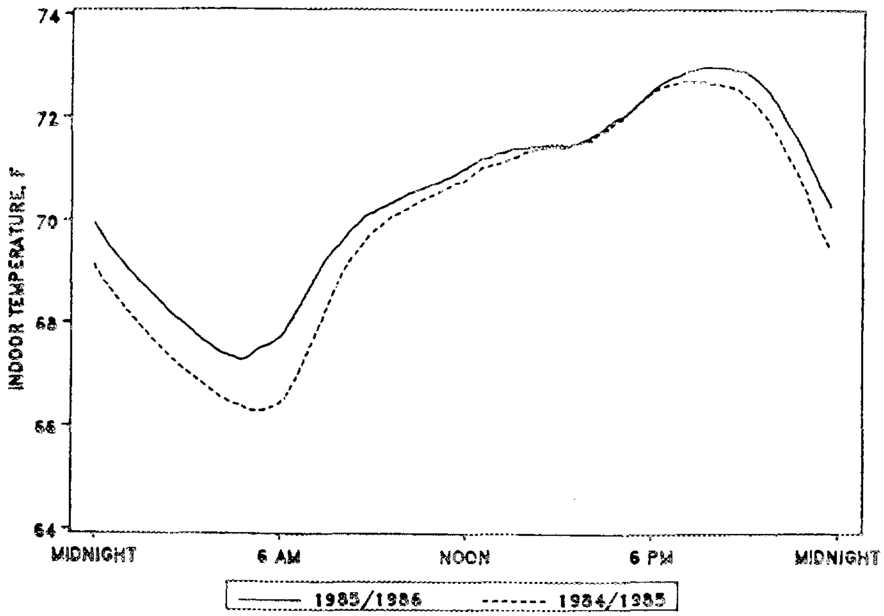

Figure A.1 Indoor temperature profiles for electrically heated homes during the pre- and post-retrofit heating seasons.*

*From Stovall and Fuller (1987)

APPENDIX B

EXAMINING DIFFERENCES IN AVERAGE INDOOR TEMPERATURE LEVELS IN THE PRE- AND POST-RETROFIT HEATING SEASONS

A very cursory way to begin to determine whether residential retrofits affect households' indoor temperature choices is to examine average indoor temperature levels recorded in the pre- and post-retrofit heating seasons. The change in average indoor temperature levels is examined for each month of the heating season (Nov., Dec., Jan., and Feb.) and for the entire heating season in order to determine if the change is statistically significant. The results of this analysis are presented in Table B.1. The variable names utilized in the table are defined as follows:

DIFNOV = The average indoor temperature level maintained in the sample homes in the month of November during the post-retrofit heating season minus the average indoor temperature level during November in the pre-retrofit heating season.

DIFDEC = The average indoor temperature level maintained in the sample homes in the month of December during the post-retrofit heating season minus the average indoor temperature level during December in the pre-retrofit heating season.

Table B.1 Differences in average indoor temperature levels in the pre- and post-retrofit heating seasons

Variable Name	Mean	Std. error of mean	t-value
DIFNOV	.4332	.1856	2.33**
DIFDEC	.3611	.2211	1.63
DIFJAN	.3864	.2372	1.63
DIFFEB	-.003	.2312	-0.01
DIFTOT	.2306	.1794	1.29

* Significant at a 90% confidence level
** Significant at a 95% confidence level
*** Significant at a 99% confidence level

DIFJAN = The average indoor temperature level maintained in the sample homes in the month of November during the post-retrofit heating season minus the average indoor temperature level during November in the pre-retrofit heating season.

DIFFEB = The average indoor temperature level maintained in the sample homes in the month of February during the post-retrofit heating season minus the average indoor temperature level during February in the pre-retrofit heating season.

DIFTOT = The average indoor temperature level maintained in the sample homes during the post-retrofit heating season minus the average indoor temperature level during the pre-retrofit heating season.

As indicated in Table B.1, the overall change in the average indoor temperature levels in the pre- and post-retrofit heating seasons (DIFTOT) is not statistically significant. When this change is examined at a monthly level, it is revealed that the change in indoor temperature levels is statistically significant only during the month of November. During this month the average indoor temperature level among all households was .43°F higher in the post-retrofit heating season than in the pre-retrofit heating season. The significant difference in pre- and post-temperatures for November may be due to outdoor weather conditions. The November of the post-retrofit heating season was the coldest November on record.

In order to determine if households that used electricity as their primary heating fuel responded differently to the retrofit than homes that used wood as their primary heating fuel, the changes in indoor temperature levels were examined for the two sub-samples of homes. The results of this analysis are presented in Table B.2.

As indicated in Table B.2, the monthly average temperature levels were not significantly different during the pre- and post-retrofit heating seasons for homes that used electricity for their primary heating fuel. The average temperature levels in wood heated homes were significantly higher in the post-retrofit season for the months of December and January and for the season as a whole. These results indicate that the level of takeback may be higher in homes that use wood as a primary fuel than in homes that use electricity as a primary fuel. This result is more fully explored in section 4.3 of this report.

Finally, differences in pre- and post-retrofit temperature levels are examined for households in alternative income categories (see Table B.3). The results of this analysis do not indicate that the average temperature levels for the heating season changed significantly for homes in any of the three income categories. However, low income households were found to have significantly warmer indoor temperature levels in the post-retrofit season during the month of November and mid income

Table B.2 Differences in average indoor temperature levels in the pre- and post-retrofit heating seasons for homes that use electricity as their primary heating fuel and for homes that use wood as their primary heating fuel

Variable Name	Mean	Std. error of mean	t-value
Electric Homes			
DIFNOV	.3704	.2246	1.65
DIFDEC	.0457	.2574	0.18
DIFJAN	.1299	.2673	0.49
DIFFEB	-.2755	.2756	-1.00
DIFTOT	.0220	.2132	0.10
Wood Homes			
DIFNOV	.3225	.2683	1.20
DIFDEC	.5900	.2865	2.06**
DIFJAN	.8157	.2957	2.76***
DIFFEB	.4402	.3138	1.40
DIFTOT	.4502	.1993	2.26**

* Significant at a 90% confidence level
** Significant at a 95% confidence level
*** Significant at a 99% confidence level

households were found to have significantly warmer indoor temperatures following the retrofit during the month of January. The results of more detailed econometric analyses; however, indicate that households in the low income category had a significantly higher level of takeback than the remainder of the sample homes. These results are discussed in Section 4.3.

As stated at the beginning of this appendix, comparisons of average temperature levels in the pre- and post-retrofit heating seasons are a very cursory approach to examining the issue of takeback. Takeback refers to the change in indoor temperature levels brought about by the increase in structural efficiency. Differences in average temperature levels in the pre- and post-retrofit heating seasons will reflect the impact of changes in electricity prices and weather conditions as well as differences in efficiency. In order to determine the level of takeback, it is necessary to sort out the individual effects that efficiency, weather, and fuel prices have on household temperature choice. Econometric methods that may be used to determine the influence of these individual effects are described in this report. The results of these models provide a more accurate picture of the level of takeback resulting from the Hood River Conservation Project.

Table B.3 Differences in average indoor temperature levels in the pre- and post-retrofit heating seasons for homes in low, mid, and high income categories

Variable Name	Mean	Std. error of mean	t-value
Low Income			
DIFNOV	.8291	.4003	2.07**
DIFDEC	.6003	.5359	1.12
DIFJAN	.2939	.5850	0.50
DIFFEB	-.1018	.6032	-0.17
DIFTOT	.2535	.4527	0.56
Mid Income			
DIFNOV	.3377	.2602	1.30
DIFDEC	.4157	.2865	1.45
DIFJAN	.5902	.3100	1.90*
DIFFEB	.1027	.2777	0.37
DIFTOT	.3633	.2356	1.54
High Income			
DIFNOV	.1783	.3065	0.58
DIFDEC	.0956	.3261	0.29
DIFJAN	.2570	.3378	0.76
DIFFEB	-.0222	.3007	-0.07
DIFTOT	.0762	.2372	0.32

* Significant at a 90% confidence level
** Significant at a 95% confidence level
*** Significant at a 99% confidence level

APPENDIX C

INDOOR - OUTDOOR TEMPERATURE RELATIONSHIPS EXPLORED

The results of the fixed effects model revealed that monthly average indoor temperature levels are significantly correlated with monthly average outdoor temperature levels in the pre-retrofit period, but not in the post-retrofit period (see Section 4.2). These results imply that the retrofits may have decreased the sensitivity of household temperature levels to outdoor temperature levels. In order to explore this hypothesis more fully, the relationship between outdoor and indoor temperature levels was explored at the daily level. Due to missing data, it was not possible to use the three micro-climate weather station specific daily outdoor temperature levels; however, average outdoor temperature levels for the county as a whole (provided by the National Oceanic and Atmospheric Administration) were utilized.

The daily average indoor temperature levels during the months of November through February for each of the monitored Hood River households (approximately 300 homes), were regressed against daily average outdoor temperature levels. These regressions were conducted for the pre- and post-retrofit periods. The results of these household specific regressions are summarized in Table C.1. In analyzing the individual regression results, households were grouped according to the types of primary and supplemental fuels that they used. The results in Table C.1 indicate the average results from the household specific regressions. For example, the average coefficient obtained by regressing daily average indoor temperature levels on daily average outdoor temperature levels for

Table C.1 Summary results of household specific univariate regressions of daily average indoor temperature levels on daily average outdoor temperature levels

Primary Fuel	Supplemental Fuel	Year	Intercept	Slope	R^2
Wood or prestologs	None	84/85	70.2***	.10	.08
Wood or prestologs	None	85/86	71.5***	.09	.15
Wood or prestologs	Electricity	84/85	69.5***	.08	.09
Wood or prestologs	Electricity	85/86	72.1***	.02	.09
Electricity	None	84/85	69.4***	.03	.11
Electricity	None	85/86	69.5***	.03	.10
Electricity	Wood or prestologs	84/85	68.5***	.06	.09
Electricity	Wood or prestologs	85/86	69.4***	.04	.10

* Significant at a 90% confidence level
** Significant at a 95% confidence level
*** Significant at a 99% confidence level

all homes that heat with wood and use no supplemental fuel is .10. The results of this analysis do not reveal a significant relationship between indoor and outdoor temperature levels in either the pre- or post-retrofit heating season.

Next, the average daily indoor temperature among all homes was regressed against daily outdoor temperature levels in the pre- and post-retrofit heating seasons. The outcome of these regressions are presented in Table C.2. When the daily average indoor temperature level for the entire sample is used as the dependent variable (as opposed to running household specific regressions), the parameter estimate on average daily outdoor temperatures is significant at a 99% confidence level in both the pre- and post-retrofit heating seasons. It is interesting to note that the size of the coefficient on outdoor temperature in the post-retrofit heating season is approximately one-half of the coefficient in the pre-retrofit heating season.

The results obtained by analyzing the relationship between indoor and outdoor temperatures at the daily average do not clearly confirm or contradict the hypothesis that the retrofits decreased the sensitivity of the houses to outdoor weather conditions. The results obtained by using the household's composite average temperature as the dependent variable indicate that household temperatures were sensitive to outdoor weather conditions in both the pre- and post-retrofit periods, and that the magnitude of that sensitivity decreased after the retrofits. This observed decrease in sensitivity is consistent with the findings of the fixed effects model. However, the summary results of the individual

Table C.2 Results of univariate regression of aggregate daily average indoor temperature levels against daily average outdoor temperature levels

Variable	Parameter Estimate	t-Value
1984/85[a]		
Intercept	69.365	247.101***
OUTTEMP	0.054	6.929***
1985/86[b]		
Intercept	70.794	366.523***
OUTTEMP	.029	5.062***

* Significant at a 90% confidence level
** Significant at a 95% confidence level
*** Significant at a 99% confidence level
a R^2 = .29
b R^2 = .18

regressions conflict with the finding that homes were sensitive to weather conditions prior to the retrofit.

These two estimation procedures are relatively simplistic methods of investigating the relationship between indoor and outdoor temperature levels. Future analysis might utilize a fixed effects model to fully exploit the time-series/cross-sectional nature of the daily indoor temperature data. These analyses could also include additional weather information, such as solar radiation and wind speed.

APPENDIX D

ADDENDUM ON PRICE ELASTICITIES

Further analysis of these data has been conducted. In this work, alternative price specifications were utilized. A Hood River specific price index was used to deflate the electricity prices, and one month lagged prices were included in the model. Both lagged real marginal prices and lagged real average prices were used. The sign on the price coefficient in each case was negative, yet not significant. The price elasticities obtained using lagged real marginal and average prices imply a temperature decrease of .2°F and .4°F, respectively, for a one cent/kWh price increase. The use of alternative price specifications produced only slight changes in the estimated level of take back.

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