SHORT RUN PRICE ELASTICITY OF RESIDENTIAL ELECTRICITY DEMAND WITHIN INCOME LEVELS AND THE IMPLICATIONS FOR CO_2 POLICY

BY
ERIC WILLIAM GREEN

THESIS
Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Natural Resources and Environmental Sciences
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2013

Urbana, Illinois

Master's Committee:
Professor William Sullivan, Chair
Associate Professor Richard Brazee
Assistant Professor Nicholas Paulson

Abstract

This thesis investigates the relationship between price and use of electricity in residential homes in order to understand the impact of CO_2 policy. A model is developed based on household, structural, regional, weather, and appliance variables. Data is collated from the Bureau of Labor Statistics, the National Oceanic and Atmospheric Administration and the Consumer Expenditure survey. The price elasticity of electricity demand is determined using generalized least squares regression analysis. Unlike other studies, the price of electricity is found to be insignificant in determining the demand of electricity. This study shows that price is only influential on demand for household incomes above $75,000. The expected impact on the residential sector of a price change from CO_2 legislation is calculated. Only a portion of the population will respond to CO_2 pricing policies, and the impact on demand for electricity of those households is low. It is determined that further investigation of the price elasticity of demand is necessary before implementing policy that uses price controls.

Table of Contents

Introduction.......... 1

Model.......... 3

Methods.......... 5

Results.......... 9

Discussion.......... 25

Summary/Conclusion.......... 29

References.......... 31

Appendix: Other Results.......... 33

Introduction

With the increased awareness of global climate change, the mitigation of carbon dioxide (CO_2) emissions has become a part of public discourse. The byproducts of energy production (CO_2, smog, etc.) are externalities that are not considered into the cost of the energy production. To account for these externalities, two legislative solutions have been proposed. One is cap and trade, which would put a limit on the amount of greenhouse gas emissions that could be produced. The second is a carbon tax, which chooses a set price for the emissions, directly raising the price of the good.

A tax on carbon would be used to raise the price, and, subsequently, reduce demand of fossil fuel based energy. Cap and trade pre-determines the allowable amount of emissions and distributes permits to industry based on this amount. Prices of energy increase because a market has been created for emissions (and there is a scarcity of permits). However, the marginal damages from greenhouse gas emissions are unknown, making it difficult to know what quantity of CO_2 is acceptable. Instead, prices (or the quantity of permits) will be arbitrarily set based on a presumed response by the consumer. These legislative solutions function only if consumer response to price is known.

The purpose of this thesis is to examine how demand for electricity changes with respect to price changes, otherwise known as the price elasticity of demand. The measure of price elasticity of demand (referred to as price elasticity) refers to the percent change in demand with a given percent change in price. The existing literature often focuses on an aggregate price elasticity measure, so this thesis also determines an aggregate price elasticity measurement for comparison. However, the discussion for the rest of the paper focuses on the hypothesis that people respond to price differently based on their income (which is different than income elasticity). After determining the price elasticity for various income groups, I briefly discuss the expected demand shift from CO_2 policy. The paper concludes with future research developments and CO_2 policy implications.

This paper focuses on a particular sector of energy consumption, namely residential electricity use. Energy costs for commercial and industrial businesses can be partially negated by passing the cost onto the customer. Residential units absorb the full price change to energy. I have chosen to analyze electricity because a large amount of CO_2 production comes from electricity demand. If carbon policy (either a tax or permit system) is put in place, residences will share a very high burden of this policy since they are the end user. I ignore other energy sources used at homes because CO_2 policy has short run impacts, which means that capital updates (because of their investment) are unlikely to occur quickly in response to price changes. Substitution of fuel types and appliances occurs over the long run (Halvorsen and Larsen 2001); in this study, other fuel types and their prices will not be considered. The omission of fuel substitutes should not influence the short-run price elasticity (Espey and Espey 2004). Moreover, Gerlagh et al. (2004) finds that demand reduction is likely to prove more useful in the short-run, as technology needs time for implementation and energy demand reduction to support alternative energy development. The focus on residential electricity consumption in the short run helps to simplify analysis and is considered an influential sector of energy consumption.

In order to determine price elasticity, I create a model for electricity demand. This model gives explanatory power to the source(s) of residential electricity demand. Using this model, price elasticity of demand can be calculated. Price elasticity has been calculated in other research, but often without a consideration to income level. The model is analyzed by controlling for certain bounds of income. Using regression analysis, the price elasticity is determined for each income group and significance of price elasticity is shown.

I begin with background regarding electricity prices and markets. I then present my methods and the model. Results are then analyzed with some comparison to similar studies. This paper ends in a discussion of the findings and the implications for CO_2 policy, and the political viability of such decisions.

Model

In order to determine a model of demand for electricity, consideration is made for how electricity is consumed. Residents utilize appliances in their home that consume electricity. These appliances are used for amenities. Some appliance use is dependent on the physical structure of the house. Demand may also be affected by characteristics of the people dwelling in the home. Use may also be influenced by exogenous factors such as the availability of other fuels, and seasonal change in temperature. Taylor (1975) emphasizes that most studies surrounding residential electricity use give consideration to other forms of energy, but since this is a short-run problem, substitution is not likely to occur which is why other forms of energy are excluded from the model. The model can account for appliances that use other forms of energy, but their impact on electricity consumption is what is observed (rather than observing changes in other forms of energy). Because consumers demand the services of appliances and structural elements of a home that rely on electricity, home consumption is assumed to be the same as demand.

The demand function used in this study is given below.

$$Consumption_i = \beta_1 + \beta_2 Price_i + \gamma_1 Household_i + \delta_1 Structural_i + \alpha_1 Weather_i + \rho_1 Regional_i + \varphi_1 Appliances_i$$

Here, household, structural, weather, regional and appliance variables are representative aggregate variables. Household includes income, age, education, family size, marriage, gender, and race. Structural variables includes home type, year the home was built, number of rooms in the home, electric water-heating, electric cooking, central air conditioning, window air conditioning, and electric heating. Weather includes cooling and heating degree days. Regional includes northeast, Midwest, south, and west. Appliances include electric stoves, gas stoves, microwaves, other stove types, built-in dishwashers, portable dishwashers, garbage disposals, clothes washers, clothes dryers, refrigerators, freezers, TVs, sound systems, computers, VCRs. It is possible that other appliances, household characteristics and structural elements could be included, but this model captures a general view of most homes and has a data set that compliments it.

In order to determine the price elasticity of electricity demand a separate model is created. A very simple model would be to use a log-log model and determine the coefficient for price.

$$\ln(D_i) = \beta_1 + \beta_2 \ln(P_i) + u_i$$

Where D is the demand for electricity and P is the price. β_2 should be the price elasticity of the function. However there is very little consensus in the literature on exactly what the functional form of energy demand (and subsequently elasticity) should take. The log-linear form calculates elasticities directly, but criticisms are made that price elasticities are not the same at all price levels (Bohi and Zimmerman 1984). There is also very little consensus on how price should enter the demand model. Poyer and Williams (1993) point out there is no consensus on whether the price measure should enter the equation contemporaneously or lagged one period or two periods. I determined that price should enter the model contemporaneously. Using the same variables, the model used to determine price elasticity and income elasticity of demand is given below in log-linear form.

$$\ln(Consumption_i) = \beta_1 + \beta_2 \ln(Price_i) + \gamma_1 Household_i + \delta_1 Structural_i + \alpha_1 Weather_i + \rho_1 Regional_i + \varphi_1 Appliances_i$$

Variations on this model are run. One variation of the model is used to compare this data set with that of Branch's (1993) results. Interactions between other variables, along with changing some non-dummy variables, were tested. Also, the model varies in controlling for region of the nation, and heating types. However, the sample size is too small to control for both (for instance, controlling for west and non-electric heat fuel only has 26 observations). One month and one-year lag price were also tested without any significant changes to the results. Finally, income levels are controlled to determine the price elasticity of demand within the four different levels. Income elasticity of demand is still calculated because of the variation of incomes within each level.

Methods

Data were collected from the 2003 Bureau of Labor Statistics (BLS) Consumer Expenditure Survey (CES) micro-data. Data is collected in two methods: self-reports and interviews. Households report their consumption or expenditures. Data was only selected from the self-reporting section. Households report or are observed by the CES for three months to one year. I selected data from fourth quarter of 2002 to first quarter of 2004.

These data were used in conjunction with 2002-2004 Consumer Price Index (CPI) data for electricity prices (per kWh). The CPI data for electricity is only available as average price. While marginal price is considered more important than average price, most consumers are not aware of marginal price, but view average price (Bohi and Zimmerman 1984). Taylor (1975) suggests that both marginal and average price be used to determine the demand function. However, no appreciable difference is detected between marginal and average price (Bohi and Zimmerman 1984). Complexity of billing, lack of information regarding price, and billing cycles being infrequent compared to usage cause most researchers to assume that the typical consumer responds to average price instead of marginal price (Carter and Milon 2005). This study uses average price provided by the CPI. CPI data are then collated with CES data.

I made the assumption that the region of the CPI data mapped directly to the regional data within the CES. CPI and CES both listed regions as Northeast, Midwest, South, and West. Population size of the city where the household was located was used to determine the price that the household would face. However, with regard to population size, CES and CPI did not map directly. Population size A in CPI data was mapped to population size 1 and 2 within CES data. Population size B/C in CPI data was mapped to population size 3, 4, and 5 in CES data. After mapping each population size and region, households had a price associated for each month.

Additionally, data are acquired from the National Oceanic and Atmospheric Association (NOAA) for determining the temperature the household faced for that month. Cooling and heating degree days (CDD and HDD respectively) are a measure of how many degrees, each day, deviated from 65 degrees Farenheit. A monthly aggregate is then determined. Nine regions (collections of states) were specified in the NOAA data set. In order to map the regions in the

CES and NOAA data, the heating and cooling degree days were averaged for the following regions: New England and Middle Atlantic, East North Central and West North Central, South Atlantic and East South Central and West South Central, and Mountain and Pacific. These averages were then associated with a specific region in the CES (Northeast, Midwest, South, and West respectively).

I use SAS as the statistical software for the arrangement of the data. Household characteristics, household demand for electricity, and appliance data are included in my analysis[1]. STATA is used to run regressions on the data.

Because of site discrimination, renters rarely have control over their appliances (Poyer and Williams 1993). For this reason, I have excluded renters from my model. Owned-home households have the ability to alter the appliance stock and building characteristics whereas rental properties are only able to adjust when the property owner chooses to alter it. Also, in a rental unit, where space or walls are shared, there is the ability to "free ride" off another's heating and cooling. This would promote bias in the parameters because of the consumer's preferences not actually aligning with their consumption. In the CES 2003 data, households were separated by type of home. Only data on single-family homes and recorded expenditure on electricity are analyzed. Other home types (such as townhouses, duplexes, high-rises, apartments, and college dorms) are ignored because the sharing of the physical structure can alter heating and cooling behaviors.

Further considerations were made with the data set. After-tax income was selected because it should comprise the disposable income of the household. 1970 was chosen as the cutoff year for when the home was built because of the energy crisis beginning in 1970 and the subsequent attention that was given to home energy consumption (particularly in the form of home insulation). Six rooms (assumed to include a kitchen, living room, 2 bedrooms, a bathroom, and a dining room) were chosen as a cutoff to separate home sizes into large and small. Sixty-five is the traditional retirement age and a retired person is more likely to be spending time in the

[1] Extra data columns are removed before saving data to csv file. CSV files are imported into Access in order to map data across files. Data is sorted for no change to cost, e.g. the bill was paid in full, (COST_=0) and interviewed person gave their full income (RESPSTAT=1). Negative income entries were eliminated from the data set.

residence and thus maintaining a more steady use of electricity. A bachelor's degree was chosen as the educational cutoff because of the assumption that exposure to more education might allow the consumer to have different consumption levels (a high school education should allow for a sufficient understanding of home economics). A family size of 2 or more was assumed to indicate the presence of children and possibly indicate more time spent in the home. All other choices and data selections were included from *a priori* information.

Table 1: Summary statistics of CES data

Variable	Minimum	Maximum	Average	Median	Standard Deviation
Demand (in kWh)	1	40080	945.23	743	999.31
Price (in $)	.074	.136	.096	.087	.018
Income (in $)	5	543957	59707.05	49400	47914.41

Table 1 contains summary statistics for a few variables in the data set. It can be quickly noted that there may be some rather large consumers of electricity, while price only fluctuates a few cents. Other variables were omitted because of their dependence on region, their variation was very small, or they entered the model as a dummy variable.

I compare income characteristics of the households in the CES data set to that of the national statistics presented in the 2000 census data (census date for 2003 was unavailable). In this way, I tried to choose income levels that would accurately portray the national statistics, while maintaining similar number of samples in each income level.

Table 2: Comparison between sample and actual distribution of population within income levels

Income Level (in USD)	Sample Size	Sample Percent of Total	US Percent of Total
0-30K	1076	28.2%	35.1%
30K-50K	860	22.5%	22.9%
50K-75K	854	22.4%	19.5%
Above 75K	1030	27%	22.5%

Once the data were collected, I used generalized least squares (GLS) regressions because ordinary least squares (OLS) estimates are inefficient due to the correlation of errors that arises from the use of panel data (Branch 1993). Reiss and White (2005) agree with Branch that OLS techniques introduce large biases. Other literature has pointed out that heteroskedasticity and multi-collinearity can be introduced with panel data. I use GLS to run the regression, adjusting for unbalanced panel data. All households are not present throughout the entirety of the data set. Thus, a weighted version of GLS is selected to compensate for the unbalanced data. The model is run using a between effects estimator. This is because the interest lies in how differences between respondents emphasizes their different consumption habits. Once the data were observed and the analysis method selected, the model was analyzed.

Results

The demand model is regressed to determine significance of variables. Significance of a variable is determined by obtaining a p-value that is less than .05. The coefficient is then used to determine the variable's impact on demand. A positive coefficient implies that as the variable increases in size, that demand for electricity will increase. A negative coefficient implies that as the variable decreases in magnitude, that demand for electricity will decrease. Calculation of demand impact is based on coefficient magnitude and direction, which varies depending on whether the variable is a dummy, interaction, or transformation. The type of variable is specified in the model section.

Table 3: Regression results from using the demand model

Variable	Coefficient	P-Value
After Tax Income	0.001	0.015*
Average Price	-2531.220	0.318
Single Family Home	132.654	0.101
Trailer Home	124.082	0.332
Electric Cooking	148.695	0.149
Electric Water Heating	(dropped)	
Built after 1970	41.683	0.398
Rooms greater than 6	125.842	0.007*
Respondent older than 65	26.755	0.643
More than Highschool Education	-127.382	0.009*
Family Size greater than 2	102.807	0.044*
Respondent is married	104.378	0.058
Respondent is male	-59.151	0.178
Respondent is white	-28.483	0.760
Respondent is black	-169.055	0.249
Electric Stove(s)	23.934	0.699
Gas Stove(s)	25.362	0.784
Microwave(s)	-80.591	0.140
Other fuel type Stove(s)	28.347	0.729
Refrigerator(s)	43.144	0.325
Builtin Dishwasher(s)	37.339	0.521
Freezer(s)	162.291	0.000*
Portable Dishwasher(s)	-84.241	0.478
Gargbage Disposal(s)	16.521	0.742
Clothes Washer(s)	-155.906	0.158
Clothes Dryer(s)	241.316	0.011*
TV(s)	10.102	0.610
Sound System(s)	62.116	0.002*
Computer(s)	26.962	0.269
VCR(s)	28.969	0.183
Cooling Degree Days	-0.128	0.810
Heating Degree Days	0.136	0.127
Electric Heating	169.380	0.056
Window AC Cooling	-97.647	0.240
Central AC Cooling	-88.024	0.226
Interaction between Cooling Degree Days and Window AC	0.758	0.288
Interaction between Cooling Degree Days and Central AC	1.098	0.040*
Interaction between Heating Degree Days and Electric Heating	0.844	0.000*
Located in Midwest	-87.935	0.431
Located in Northeast	(dropped)	
Located in South	299.115	0.014*
Located in West	62.193	0.402
Constant	204.596	0.568

Number of Observations = 3816
R-sq = .207

* - p-value $<$ .05

Coefficient : magnitude and direction of impact the variable has on the demand for electricity

Table 3 displays the regression results from using the model for determining the demand for electricity. The income variable has a positive and significant effect on demand. This agrees with the assumption that electricity is a normal good. Reiss and White (2005) determine that a household's demand is not significantly dependent on income when accounting for appliances, since income correlates with type and amount of appliances. Dummy variables regarding family size and number of rooms also share a positive and significant effect. Each individual will consume some amount of electricity that is personal to them, and a home with more rooms will require more lighting and/or space heating to maintain its comfort level. Education has a significant and negative effect on demand. Price, as shown in Table 3, is insignificant when predicting demand. Freezers and clothes dryers have a significant impact on demand because of the intensive energy use of those appliances[2]. That sound systems have a positive and significant effect on the demand for electricity may indicate that those households desiring high quality entertainment also put much more value on entertainment that requires electricity. The interactions of heating degree days and cooling degree days with their respective heating and cooling element are positive and significant; it is not only the fact that, for instance, heating is electrically based, but also the number of days that heating is required which determines the impact on demand. The national location of the home being in the south as being significant and positive is explained by the prevalence of electricity as the primary fuel source in that area of the country[3]. Electric water heating is dropped from the model because of its correlation between electric cooking and electric heating. Northeast is dropped because all other regions are accounted for; this means that for significance to be assigned to another regional variable, there are not enough degrees of freedom available to maintain northeast as a part of the model. The same would occur if a female variable was included.

[2] http://aceee.org/consumer

[3] While the bounds of the region are not defined within the CES, http://www.eia.gov/dnav/ng/ng_cons_pns_a_EPG0_VRP_pct_a.htm indicates less natural gas use by "southern" states.

Table 4: Regression results from using the elasticity model

Variable	Coefficient	P-Value
Income Elasticity	-0.060	0.050*
Price Elasticity	-0.050	0.866
Single Family Home	0.163	0.074
Trailer Home	0.047	0.746
Electric Cooking	0.367	0.002*
Electric Water Heating	(dropped)	
Built after 1970	0.042	0.451
Rooms greater than 6	0.137	0.009*
Respondent older than 65	-0.008	0.908
More than Highschool Education	-0.141	0.010*
Family Size greater than 2	0.132	0.022*
Respondent is married	0.202	0.001*
Respondent is male	-0.089	0.070
Respondent is white	-0.027	0.795
Respondent is black	-0.192	0.245
Electric Stove(s)	-0.040	0.567
Gas Stove(s)	0.131	0.208
Microwave(s)	-0.028	0.652
Other fuel type Stove(s)	0.104	0.257
Refrigerator(s)	-0.001	0.982
Builtin Dishwasher(s)	0.137	0.037*
Freezer(s)	0.210	0.000*
Portable Dishwasher(s)	-0.009	0.946
Gargbage Disposal(s)	0.031	0.582
Clothes Washer(s)	0.009	0.943
Clothes Dryer(s)	0.287	0.008*
TV(s)	0.015	0.498
Sound System(s)	0.085	0.000*
Computer(s)	0.044	0.111
VCR(s)	0.003	0.887
Cooling Degree Days	-0.001	0.132
Heating Degree Days	0.000	0.323
Electric Heating	0.155	0.120
Window AC Cooling	-0.045	0.627
Central AC Cooling	0.054	0.508
Interaction between Cooling Degree Days and Window AC	0.002	0.011*
Interaction between Cooling Degree Days and Central AC	0.002	0.007*
Interaction between Heating Degree Days and Electric Heating	0.001	0.000*
Located in Midwest	0.042	0.749
Located in Northeast	(dropped)	
Located in South	0.476	0.001*
Located in West	0.159	0.057
Constant	5.416	0.000*

Number of Observations = 3816
R-sq = .248

* - p-value < .05

Coefficient : magnitude and direction of impact the variable has on the elasticity of demand for electricity

Table 4 presents the results of regressing the model of elasticity of demand. The effect of income on demand for electricity is significant and has a negative effect. This is not consistent with the findings from the linear specification results given that income's estimated effect on demand was significant. This would suggest that with a 1% change in income, demand would decrease by .06%. Espey and Espey (2004) find that income elasticity is lower when including the appliance stock. Having income elasticity with an unexpected sign, along with the insignificance of price elasticity, have indicated that the model may not be capable of fully explaining the relationships between the variables and the demand for electricity.

Table 5 highlights studies that were examined for income and price elasticities along with their methodology. Each study that is presented in Table 5 has a significant income and price elasticity. The findings from other studies, presented in Table 5, do not agree with my finding that price elasticity of demand is not significant.

Table 5: Price and income elasticities reported in published studies

Study	Method	Price Elasticity	Income Elasticity
Branch (1993)	Log-Linear	-.20	.23
Espey and Espey (2004)	Meta-regression	-.35	.28
Halvorsen and Larsen(2001)	Two-step Discrete/Continuous	-.433	.13
Maddala et. Al (1997)	Dynamic Linear Regression	-.196	.137
Nakajima and Hamori (2010)	Log-Linear	-.33 dropping to -.14	.38 increasing to .85
Poyer and Williams (1993)	Variant on Log-Linear	-.42 thru -.81	.1 thru .17
Reiss and White (2005)	Generalized Method of Moments	-.39	0.00

Espey and Espey's (2004) study was a meta-analysis of 36 studies in order to determine the cause of differences between results of price and income elasticities. It is the most comprehensive study to date, including an analysis of variations between studies. Branch (1993) uses an older version of the data set that I used, and a similar model that is described in more detail later on. Halvorsen and Larsen (2001) conduct a long run study and also include other fuel types and their prices. Maddala et. al (1997) focused on identifying coefficients for price and income elasticity in both the short and long run. Nakajima and Hamori (2010) compare elasticities before and after deregulation in the US. Poyer and Williams (1993) explores race and other social factors impact on electricity consumption. Reiss and White (2005) conducted their own study of Californian electricity consumption.

Espey and Espey (2004) confirm that use of average price instead of marginal price results in a larger elasticity estimate. Likewise, Taylor (1975) suggests if average and marginal price are positively correlated (as is likely to be the case), then use of one of the prices in absence of the other will lead, in general, to an upward bias in the estimate of the price elasticity and a bias in income elasticity (direction not noted). I use average price, but find no effect on the price elasticity (but this may be significant for findings when observing different income levels). National data tends to have a larger elasticity than regional data. In this case, it is expected that my price elasticity estimates would be higher than those of Reiss and White (2005) since theirs is a regional study of California. Espey and Espey (2004) find that including temperature will find more elastic income estimates. I do not find price to be more elastic, but rather that it is insignificant. This concludes that a percent change in price has no percent change on demand.

I tested different models, which included variations on changing dummy variables for age, number of rooms, and family size to per unit variables. Also, several interactions were tested as well: between price and heating fuel type, price and window unit, price and central air, price and cooling degree days, price and heating degree days, price and cooling degree day and window unit, price and cooling degree day and central air, price and heating degree day and heat fuel type, and price and income. The final selection included all of the above interactions and altering the dummy variables. The interaction between cooling degree days, price and air conditioning and heating degree days, price and electric heating are necessary because they capture the major swings in appliance use based on price change with consideration to temperature fluctuations. The decision was based on overall fit of the model, determined by the R^2 result.

Table 6: Regression results from using the demand model including additional interaction variables

Variables	Coefficient	P-Value
After Tax Income	0.007	0.001*
Interaction between Price and Income	-0.062	0.005*
Average Price	4523.700	0.415
Single Family Home	128.014	0.116
Trailer Home	132.808	0.299
Electric Cooking	178.003	0.085
Electric Water Heating	(dropped)	
Built after 1970	33.028	0.505
Number of Rooms	36.514	0.006*
Age of Respondent	0.206	0.899
More than Highschool Education	-116.741	0.020*
Family Size	50.897	0.017*
Respondent is married	65.370	0.269
Respondent is male	-46.460	0.291
Respondent is white	-20.348	0.826
Respondent is black	-161.803	0.268
Electric Stove(s)	14.600	0.813
Gas Stove(s)	38.515	0.677
Microwave(s)	-85.760	0.117
Other fuel type Stove(s)	48.131	0.556
Refrigerator(s)	52.201	0.240
Builtin Dishwasher(s)	29.864	0.610
Freezer(s)	171.652	0.000*
Portable Dishwasher(s)	-61.871	0.603
Gargbage Disposal(s)	13.185	0.792
Clothes Washer(s)	-183.407	0.097
Clothes Dryer(s)	248.757	0.009*
TV(s)	0.999	0.960
Sound System(s)	58.043	0.004*
Computer(s)	25.228	0.299
VCR(s)	32.948	0.136
Cooling Degree Days	6.971	0.101
Heating Degree Days	0.199	0.690
Electric Heating	-553.727	0.290
Window AC Cooling	339.964	0.480
Central AC Cooling	-50.781	0.906
Interaction between Price and Electric Heating	7991.520	0.144
Interaction between Price and Window AC	-4268.430	0.366
Interaction between Price and Central AC	-77.476	0.985
Interaction between Cooling Degree Days and Window AC	-5.025	0.349
Interaction between Cooling Degree Days and Central AC	-4.706	0.273
Interaction between Heating Degree Days and Electric Heating	2.973	0.002*
Interaction between Price and Cooling Degree Days	-68.829	0.097
Interaction between Price and Heating Degree Days	-0.530	0.921
Interaction between Price, Cooling Degree Days, and Window AC	56.880	0.292
Interaction between Price, Cooling Degree Days, and Central AC	55.161	0.189
Interaction between Price, Heating Degree Days, and Electric Heating	-23.151	0.021*
Located in Midwest	-380.253	0.000*
Located in Northeast	-290.995	0.022*
Located in South	(dropped)	
Located in West	-252.387	0.017*
Constant	-442.704	0.442

Number of Observations = 3816
R-sq = .215

* - p-value < .05

Coefficient: magnitude and direction of impact the variable has on the demand for electricity

The results from this new model (displayed in Table 6) show that many of the same variables are significant and in the same direction as previous models. The first difference is that cooling degree days (and all the interactions) are not significant. However, the fact that the south variable is dropped, and other areas of the U.S. (which would have much more emphasis on heating) show significant negative response, indicates that cooling in those areas is less of a priority while heating from natural gas is likely to be more prevalent. The price and heat fuel type and heating degree day is significant and negative, which would imply that while heating degree days and heat fuel type will increase the amount of electricity consumed, that it is not as important as conserving when prices become high. This is also indicated in the price and income interaction, that it was significant and negative. That while income may be increasing, price stills plays a part in determining how much electricity to use.

Table 7: Regression results from using the elasticity model including additional interaction variables

Variables	Coefficient	P-Value
Income Elasticity	-0.320	0.364
Elasticity of Price interacted with Income	-0.110	0.458
Price Elasticity	1.574	0.358
Single Family Home	0.162	0.077
Trailer Home	0.045	0.755
Electric Cooking	0.388	0.001*
Electric Water Heating	(dropped)	
Built after 1970	0.041	0.458
Number of Rooms	0.021	0.167
Age of Respondent	-0.001	0.757
More than Highschool Education	-0.110	0.050*
Family Size	0.077	0.001*
Respondent is married	0.149	0.026*
Respondent is male	-0.081	0.104
Respondent is white	-0.012	0.907
Respondent is black	-0.188	0.256
Electric Stove(s)	-0.050	0.475
Gas Stove(s)	0.137	0.189
Microwave(s)	-0.034	0.578
Other fuel type Stove(s)	0.123	0.182
Refrigerator(s)	0.015	0.770
Builtin Dishwasher(s)	0.140	0.034*
Freezer(s)	0.220	0.000*
Portable Dishwasher(s)	0.016	0.906
Gargbage Disposal(s)	0.030	0.596
Clothes Washer(s)	-0.029	0.816
Clothes Dryer(s)	0.297	0.006*
TV(s)	0.014	0.535
Sound System(s)	0.080	0.000*
Computer(s)	0.043	0.119
VCR(s)	0.006	0.810
Cooling Degree Days	0.004	0.349
Heating Degree Days	0.000	0.430
Electric Heating	-0.717	0.225
Window AC Cooling	0.281	0.606
Central AC Cooling	0.132	0.784
Interaction between Price and Electric Heating	9.435	0.127
Interaction between Price and Window AC	-3.214	0.547
Interaction between Price and Central AC	-0.620	0.894
Interaction between Cooling Degree Days and Window AC	-0.002	0.704
Interaction between Cooling Degree Days and Central AC	-0.000	0.967
Interaction between Heating Degree Days and Electric Heating	0.003	0.015*
Interaction between Price and Cooling Degree Days	-0.053	0.255
Interaction between Price and Heating Degree Days	-0.004	0.542
Interaction between Price, Cooling Degree Days, and Window AC	0.043	0.479
Interaction between Price, Cooling Degree Days, and Central AC	0.015	0.747
Interaction between Price, Heating Degree Days, and Electric Heating	-0.021	0.065
Located in Midwest	-0.436	0.000*
Located in Northeast	-0.450	0.002*
Located in South	(dropped)	
Located in West	-0.326	0.009*
Constant	9.543	0.020*

Number of Observations = 3816
R-sq = .251

* - p-value < .05

Coefficient : magnitude and direction of impact the variable has on the elasticity of demand for electricity

In examining the elasticity of demand results from Table 7, income and price are shown to have coefficients with signs that would indicate that as price increases more electricity is consumed, and as income increases less electricity is consumed. However, they are insignificant along with their interaction, but their interaction still carries the expected sign. While some variables that were significant in the demand model no longer are for the elasticity model, a few other variables have become significant. The dummy variable for marriage became a significant factor in determining the demand for electricity, which would imply that marriage has a small impact on percent demand increase. According to the results of the regression analysis, the act of marriage in some way changes behavior of the occupants such that being married increases demand for electricity. However, these data and analysis are not capable of separating out behavioral change from changes in occupancy of the household. This may also be related to the increase in demand based on cooking and the built in dishwasher. Some attention should be given to the significance of the constant. This would suggest that percent changes in demand were most affected by the base usage of electricity. Most studies do not find the constant to be of significance, and it is often viewed as an indicator that there are still explanatory variables missing from the model (Branch 1993, Espey and Espey 2004, Halvorsen and Larsen 2001, Maddala et. al 1997, Nakajima and Hamori 2010, Poyer and Williams 1993, Reiss and White 2005). Because the constant was not viewed as significant in the demand model, this is viewed as a household's resistance to reduction in consumption (because of its positive nature).

Parsing the data set by heating types, electric and non-electric, revealed no significant differences of variables contributing to the demand for electricity. When controlling for non-electric fuel types, there was no difference between significance of variables and the regression results (in Table 7) for the elasticity model with additional variables Controlling for electricity as the heating type did yield differences in the significance of variables, but because the sample size of the two regressions is so much smaller, the significance of the variables may be suspect. They can be viewed in Appendix A.

Next the model was tested controlling for area of the country. These new regressions did not reveal any new findings regarding variables and their impact on the demand or the elasticity of demand for electricity. The results can be viewed in Appendix A.

Next, the original model was tested by parsing the data by income levels. This is done to test if people in different income levels show different sensitivities to the price of electricity. A consolidated set of results is listed in the table below (the full results can be seen in Appendix A).

Table 8: Price elasticities and consumption of income ranges

Income Range (in USD)	Price Elasticity	P-value of ln(price)	Average Consumption	Median Consumption	Std. of Consumption
0-30K	-.49	0.447	852 kWh	677 kWh	703 kWh
30-50K	.35	0.605	883 kWh	684 kWh	816 kWh
50-75K	-.12	0.819	975 kWh	798 kWh	745 kWh
Above 75K	-1.36	0.045	1070 kWh	843 kWh	1465 kWh

The most interesting finding is that the only income group that has price as a significant variable for determining demand is the highest income bracket. The price elasticity of demand for electricity is three times larger than the findings in Table 8. This would suggest that for a 1% increase in price, demand will decrease by 1.36%. It should be noted that a 100% demand reduction cannot be achieved by a 100% change in price because price elasticities are not constant along the demand curve.

Prasad (1983) notes that as income increases, price elasticity becomes more elastic[4] (percent change in demand is greater than the percent change in price), but then shifts to becoming more inelastic. When controlling for income, this study shows that any household with an income of less than $75,000 does not change their demand for electricity when price increases. Price elasticity of demand being inelastic can be ignored due to the overwhelming finding that price elasticity is not significant, except at high incomes. At high incomes, it is found that price elasticity of demand for electricity is very elastic. This finding is contrary to Reiss and White's (2005) premise that, as income rises, that households tend to move towards more price-inelastic

[4] Elastic refers to a large change in demand with a change in price. Inelastic refers to a very small change in in demand with a change in price.

electricity use. Table 8 shows the average, median, and standard deviations for each of the income levels. Not only are higher incomes using more energy, but they also have the most flexibility to change their behavior in response to price changes.

The results from Table 8 can be compared with Reiss and White's (2005) Table 4 (shown below).

Table 9: Table 4 from Reiss and White (2005)

Price elasticities by household income and electricity consumption

Quartile	Quartile range	Price elasticity[a] GMM method	Price elasticity[a] OLS method
By household annual income level:[b]			
1-st	Less than $18,000	−0·49	+0·15
2-nd	$18,000 to $37,000	−0·34	+0·17
3-rd	$37,000 to $60,000	−0·37	+0·14
4-th	More than $60,000	−0·29	+0·17
By household annual electricity consumption:			
1-st	Less than 4450 kWh	−0·46	+0·37
2-nd	4450 to 6580 kWh	−0·35	+0·04
3-rd	6580 to 9700 kWh	−0·32	−0·00
4-th	More than 9700 kWh	−0·33	−0·08

[a] Mean annual electricity price elasticity for households within each quartile.
[b] Approximate California household income quartiles, in 1998 dollars.

The income ranges that Reiss and White (2005) identify are not the same as those I have identified in Table 8. While these different income ranges would likely affect the size of the coefficients of price elasticity, it is not likely to affect the significance. It may be difficult to adjust the data used in this study to have similar income ranges as Reiss and White (2005) because of the number of data points would be unbalanced. Unbalanced data would cause an issue with potentially not having enough data points to prove significance but also loses the ability to correlate with national level statistics as shown in Table 2. Also, the 0-75K (USD) income ranges are insignificant, for determining demand, at a p= 0.05 level. This may mean that other variables have a higher influence on percent demand change (perhaps saturation of some appliance level occurs during these income brackets) or that households are achieving some level of comfort that is both affordable and desired. Reiss and White (2005) do not provide p-values for their elasticity measurements, though it can be discerned that the OLS measurements are likely to be insignificant since they are displaying a sign that would indicate an increase in price would yield an increase in demand. Reiss and White (2005) report that low-income households are more price sensitive than high-income households. Their result is directly challenged by this study, which suggests that the only group that is responsive to price is the high-income group.

Because of the differences between the results in this study and other studies, the model was altered to reflect that of Branch (1993). Branch used a similar data set, and methods for analysis. The following are differences between variables that were included: Branch (1993) included children under the age of 6 and adults over the age of 65 (this data was not available), CPI prices are lagged one month in Branch (1993), income was determined by total expenditure instead of being reported directly, appliances in Branch (1993) were only reported as dummies and not total number, heating and cooling options were consolidated in more current versions of the data set, and Branch (1993) included seasonal variables along with cooling and heating degree days.

Table 10: Regression results using Branch's (1993) model

Variable	Coefficient	P-Value
Income Elasticity	-0.063	0.033*
Lagged Price Elasticity	-0.116	0.695
Electric Water Heating	(omitted)	
Built after 1970	0.045	0.406
Number of Rooms	0.036	0.010*
Age of Respondent	-0.001	0.472
Family Size	0.111	0.000*
Respondent is Married	0.098	0.122
Electric Stove Present	0.192	0.000*
Microwave Present	-0.008	0.916
Freezer Present	0.286	0.000*
Built in Dishwasher Present	0.203	0.002*
Portable Dishwasher Present	0.074	0.581
Garbage Disposal Present	0.021	0.716
Clothes Dryer Present	0.294	0.000*
Interaction between Cooling Degree Days and Window AC	0.001	0.154
Interaction between Cooling Degree Days and Central AC	0.001	0.001*
Interaction between Heating Degree Days and Electric Heating	0.001	0.000*
Located in Midwest	-0.075	0.502
Located in Northeast	-0.169	0.033*
Located in South	0.330	0.007*
Constant	5.495	0.000*

Number of Observations = 3816
R-sq = .221

* - p-value < .05

Coefficient : magnitude and direction of impact the variable has on the elasticity of demand for electricity

These should be compared to Branch's (1993) results below.

Table 11: Table 1 from Branch (1993) for results of estimating short run demand for residential electricity

Independent Variable	Generalized least squares[a]		
	Coeff.	Standard Error	P-value
Intercept	2.4600	0.3237	[b]
Log total expenditure	0.2343	0.0323	[b]
Log average price	-0.2045	0.0544	0.0002
Number of rooms	0.0406	0.0094	[b]
Household size	0.0782	0.0108	[b]
Age of reference person	0.0030	0.0011	0.0053
Marital status of reference person	0.0700	0.0367	0.0565
Northeast dummy	-0.0711	0.0537	0.1857
Midwest dummy	0.0199	0.0388	0.6071
South dummy	0.0390	0.0432	0.3663
Winter dummy	0.1413	0.0178	[b]
Summer dummy	0.0433	0.0196	0.0273
Fall dummy	0.0556	0.0186	0.0028
Electric heat dummy and heating degree days	0.0012	0.0001	[b]
Air conditioning dummy and cooling degree days	0.0010	0.0001	[b]
Central air dummy and cooling degree days	0.0007	0.0001	[b]
Electric water heater dummy	0.3649	0.0401	[b]
Central forced air furnace dummy	0.1215	0.0357	0.0007
Gravity forced air dummy	0.1514	0.1259	0.2290
Wall furnace with heat pump dummy	0.1655	0.1488	0.2661
Central system with heat pump dummy	-0.0178	0.1086	0.8700
Room heater with flue dummy	0.1983	0.1072	0.0644
Room heater without flue dummy	0.1261	0.1119	0.2598
Electric stove dummy	0.1384	0.0312	[b]
Microwave oven dummy	0.0295	0.0319	0.3547
Freezer dummy	0.2348	0.0307	[b]
Clothes dryer dummy	0.1314	0.0420	0.0017
Built-in dishwasher dummy	0.0883	0.0503	0.0788
Portable dishwasher dummy	0.0388	0.0387	0.3157
Garbage disposal dummy	-0.0199	0.0355	0.5756

Note: [a]Residual variance = 0.137; group variance = 0.151; log likelihood = -2550.55.
[b]P-value is less than 0.0001.

Table 10 and Table 11 are now compared. While income is significant in both tests, it is negative in this particular model. Branch's (1993) finding was similar to that of other studies in finding a positive coefficient, indicating increasing demand for electricity with increasing income. Branch (1993) had earlier postulated that in models where appliances are not controlled, the income elasticity is likely to be much higher. In fact, using a model similar to Branch's (1993) model, wherein the appliances were entered as dummy variables, altered the direction of the income elasticity. The change in number of variables and what the variables account for has also changed the direction of the income coefficient in my results. Another point at which our studies differ is with price elasticity, particularly with significance. In Branch's (1993) price elasticity is significant and negative, indicating an inelastic reduction in demand with price change. We also differ on the significance of the age of the respondent. This variable, even when significant, affects demand very little. The interaction between window units and cooling degree days is no longer significant in my study. Another striking difference is that none of Branch's (1993) geographical dummy variables are significant, whereas the same variables in this study play a significant role. This model may not be capable of capturing larger social changes that may have occurred since the development of Branch's (1993) model. This comparison indicates that even using closely related methods, the dataset of the 2003 Consumer Expenditure Survey is yielding drastically different results than the 1985 data.

The findings of this study do not immediately agree with all other findings. Significant variables, for determining the demand for electricity, are either appliances or household characteristics instead of income and price. However, the insignificance of price and income warrants discussion.

Discussion

The first significant finding is that air conditioning does not significantly impact demand for electricity but household heating does. This study shows that people are unwilling to change their use of air conditioning, regardless of whether a price change in electricity should occur. This suggests that either air conditioning is not viewed as a luxury good, or that households behave based on a set of beliefs or culture of use of air conditioning (Reiss and White 2008). However, heating does not appear to be utilized in the same way. When price is included with the interaction of electric heating and the heating degree days, a negative response to demand occurs. This would suggest that people are reducing their demand for electricity when price is increasing, despite demand for electricity to provide heating. Though, the elasticity of demand is not actually affected, which would suggest that heating can be reduced only so far, and a large swing in price may not elicit a large change in heating demand.

This study also finds that as income increases, electricity usage will increase. The model distinguishes between appliance number and income, indicating that income has some effect on behavior. Unfortunately, the model is not capable of capturing this behavioral change.. However, the magnitude of the coefficient is extremely small, indicating that increased income may not result in direct consumption increase. Instead, purchases are made that consume more electricity (either adding more appliances or using appliances longer). Income elasticity is insignificant when taking into account housing appliance stock. This implies that there is no percent change in demand with a percent change in income. This is significant because focus can be placed on use of appliances as well as other behavioral techniques to adjust demand.

Even more striking is that price is insignificant when predicting demand. This is highly unexpected, not only because of the overwhelming evidence from other studies (Branch 1993, Espey and Espey 2004, Halvorsen and Larsen 2001, Maddala et. al 1997, Nakajima and Hamori 2010, Poyer and Williams 1993, Reiss and White 2005), but also because it contradicts the standard economic assumption that price and demand are related (Nicholson and Snyder 2008). Finding that price elasticity is also insignificant means that percent change in price does not lead to percent change in demand. This finding means that altering price is not a good method by which to alter demand.

When comparing the price elasticity across income, the model shows price elasticity is insignificant for the first three income groups (0-75K USD), but becomes significant for the last level (over $75K). While it may seem unintuitive that a person who has very little in the way of disposable income would not pay attention to prices, it may mean that other factors (such as education, culture, existing housing stock) all play a larger role. Unfortunately, there are not enough data points to control for education within the income brackets. Also, the lowest income levels may be using the least amount of electricity they can, and only by changing their housing stock (either the physical structure or the appliances within) can they alter demand. The fact that the constant is significant in the model would suggest that there is base level of use that consumers are hesitant to reduce. This would lend value to why price is ineffectual in shifting demand: once a household becomes accustomed to use, they are unwilling to move away from that level of utility, but instead would rather shift their budget to compensate.

This study confirms that people of different income levels respond to price changes differently. However, in contrast with the findings of previous studies (Branch 1993, Espey and Espey 2004, Halvorsen and Larsen 2001, Maddala et. al 1997, Nakajima and Hamori 2010, Poyer and Williams 1993, Reiss and White 2005), this study shows that people of lower income levels do not respond to price changes while upper income levels do. The results of this study challenge the idea, from Reiss and White (2005), that the highest income bracket is the most inelastic. The highest income bracket consumes, on average (see Table 8), the most electricity, and thus have the ability to change their demand the most. Moreover, higher income individuals own and utilize more appliances and therefore more easily reduce consumption, in response to price changes. A comparison of appliances can be seen in Table 12 below. The highest income bracket owns, on average, two more appliances than the income level below them. Further investigation could be given to identifying what these appliances are, and if they are considered essential for comfort.

Table 12: Appliance statistics by income range

Income range (in USD)	Number of respondents with zero appliances	Average number of appliances	Median number of appliances	Std. of appliances
0-30K	37	10.6	11	4.6
30-50K	33	12.5	12	4.4
50-75K	29	13.5	14	4.6
Above 75K	42	15.5	15	5.5

These findings have strong implications for CO_2 policy that relies on price to reduce demand. A tax on CO_2 would create an increase in the price of electricity (Metcalf 2007). Using a cap and trade system would require establishing a market before a price shift would occur (Metcalf 2007). In either case, a price shift can be assumed.

Metcalf (2007) notes that a $15/ton CO_2 tax (at the fuel source) would yield a 1.58 cent/kWh[5] increase. Using the national average price for electricity in 2003, 8.73 cent/kWh[6] and an 1.58 cent/kWh price increase results in an 18.1% increase in price. Using this estimated increase, this model predicts a 24.6% decrease in demand for the upper income tier of the population according to Table 8. All other consumers would be non-responsive to this price shift. While the upper tier is only accounting for 27% of the sample, they account for 36% of the electricity consumption in the sample. Adjusting this to reflect national statistics[7], households with an income over $75,000 use approximately 29% of the nation's residential electricity.

Total U.S. CO_2 emissions from residential electricity use in 2003 were 880 million metric tons (MMT) of CO_2.[8] However, this is from the site use of electricity, so using primary electricity consumption numbers[9], emissions are 2400 MMT of CO_2. 29% of the total residential emissions

[5] adjusted for inflation from 2007 to 2003 dollars
[6] from Sales and Revenue Data by State, Monthly Back to 1990 (Form EIA-826) located at http://www.eia.gov/electricity/data.cfm#sales
[7] http://www.census.gov/main/www/cen2000.html
[8] Using $6.8956x10^{-4}$ metric tons CO_2/kWh from http://www.epa.gov/greenpower/pubs/calcmeth.htm#kilowatt and 1.276 trillion kWh of residential electricity sales from Sales and Revenue Data by State, Monthly Back to 1990 (Form EIA-826) located at http://www.eia.gov/electricity/data.cfm#sales
[9] Extrapolating from 2001 primary electricity consumption with an average growth of 1.2%/year from http://www.eia.gov/emeu/efficiency/2005_usaee.pdf

are 696 MMT of CO_2. The projected 24.6% reduction from a price shift would yield a total reduction of 171 MMT of CO_2.

According to this study, a carbon tax of $15/tonne of CO_2 would reduce residential electricity demand by 7%, or reduce emissions by 171 MMT of CO_2. The Intergovernmental Panel on Climate Change (IPCC) has recommended reducing CO_2 emissions to 80% of 1990 levels (approximately 1000 MMT of CO_2)[10]. In 2003, total emissions were 7065 MMT of CO_2[11]. Thus, an increase of 18.1% in residential electricity prices alone yields 2.9% of the IPCC's recommended reduction of CO_2 emissions.

Reiss and White (2008) suggest an effective measure for conservation would be to target high consumption households, as they are easily identified and a small share of the population. This study reveals that high-income households are price responsive and will likely reduce their electricity consumption. According to the price elasticity of demand for residential electricity, the overall effect of the change will reduce CO_2 emissions by 2.9% (using a $15/ton of CO_2 tax). Because other industries are outside the scope of this paper, the effect of the tax's impact on CO_2 production is unknown.

Moreover, since the method for encouraging conservation of both types of carbon policies is an increase in price, each carries with it the potential to act as a regressive policy. Shammin and Bullard (2009) show that carbon policy is likely to have a disproportionately greater impact on low-income households. Carbon taxes can often be regressive because a flat rate tax on energy represents a greater proportion of lower incomes than higher. Metcalf (2007) finds that a cap and trade system with grandfathered permits is regressive because most of the wealthier households hold equity and when real income declines for the lowest income levels, it increases for the top two deciles. In fact, the results of this study indicate that a low-income household would not adjust demand, thereby taking on the full cost of the regulation, which can only be paid for out of disposable income (or by replacing another cost).

[10] http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm
[11] http://www.epa.gov/climatechange/emissions/usgginventory.html

Summary/Conclusion

Without knowing the price elasticity of demand for electricity of residential households, it is impossible to determine what the reduction in the demand for electricity of any carbon reduction policy will be. However, this study only observes the impact of price of electricity on demand, but does not reflect the consumer's knowledge about price. CPI data is linked to CES data to estimate the price the household faced. CES data captures the consumer's expenditure, but not their knowledge of the price of electricity. If consumers are often using total cost/expenditure of electricity as the means to determine their elasticity, the elasticity of expenditure should be analyzed. However, this poses difficulties, as expenditure on electricity is a function of both demand and price. This study does not capture what price information the consumer has or the consumer's ability to derive price from expenditure. Other studies have investigated the effect of price information on price elasticity, and this could be incorporated into future models (Reiss and White 2008, Leighty, Wayne and Alan Meier 2011).

Further, the model could incorporate marginal price as well as price schedule. This would only be possible if the price schedule was also made available. Data collection through technological monitoring would be useful, allowing for Taylor's (1975) recommendation that a database with both marginal and average price, for different states, linked to the price schedule for the household, be constructed. If consumer faces a block rate price schedule, a discrete-continuous choice model (Olmstead 2009) would be useful in estimating price elasticity. While price schedules impact the price elasticity of demand for electricity, this study does not incorporate price schedule into the model because it was not available. Price elasticity estimates are necessary for efficient rate pricing, but design of the price schedule can extremely influence what the household observes as the price of electricity they face (Carter and Milon 2005).

Large price increases in short periods of time have shown to have an influence on demand for electricity. This data set contains price that varies between \$0.074 and \$0.136. This implies that no more than a 100% change can occur in price, and this generally occurs over the course of seasonal changes. Taylor (1975) offers a hypothesis that sharp increases in price, as can be seen in energy crises, would produce "non-quantifiable influences such as a conservation ethic". Reiss and White (2008) are able to note that significant behavioral change occurred during the

Californian energy crisis. A large portion of California's demand for electricity comes from appliances that cannot be changed in the short run (freezers, refrigerators, etc.); demand reductions came from reduced amenities, such as air conditioning (Reiss and White 2008). In order to maintain a level of reduced demand, the price must remain high. Leighty and Meier (2011) reaffirm this by observing a supply interruption in Alaska. With a price increase of about 500%, conservation spread rapidly. However, when supply returned, consumption rose. The rebound effect is apparent from the California energy crisis; consumer demand returned to almost its original level after the price declined from its spike (Reiss and White 2008). The persisting demand reduction in Leighty and Meier (2011) was primarily from technology that was implemented during the price shock. Further study of larger rate increases may be necessary to understand how price may influence consumption. This may be useful when considering structures of CO_2 policy.

A compelling finding within this study is that price elasticity of demand for electricity is not significant in the aggregate model. Even more compelling, price elasticity is found to be elastic for high incomes. Slight changes to the price of electricity are likely to have very large effect on the highest income bracket. Knowing price elasticity is extremely important for determining efficient price setting, and also in developing policy regarding electricity prices. For the purposes of this thesis, understanding the elasticity of demand allows us to estimate the change in CO_2 demand based on price changes from CO_2 policy. With further understanding of other industries, the efficacy of CO_2 policy could be evaluated. A strong CO_2 policy could have wide reaching effects, even beyond the residential end-user. A more aggressive price adjustment from CO_2 policy will likely be necessary to make significant impact from the residential end-user.

References

Bohi, Douglas R. and Mary Beth Zimmerman (1984). An update on econometric studies of energy demand behavior. Annu Rev Energy. v.9: 105-154

Branch, E. Raphael (1993). Short run income elasticity of demand for residential electricity using Consumer Expenditure Survey data. Energ J. v.14 (4): 111-122

Carter, David W. and J. Walter Milon (2005). Price knowledge in household demand for utility services. Land Econ. v.81 (2): 265-283

Espey, James A. and Molly Espey (2004). Turning on the lights: A meta-analysis of residential electricity demand elasticities. J Agr Appl Econ. v.36 (1): 65-81

Gerlagh, Reyer, Bob Van Der Zwaan, Marjan W. Hofkes, and Ger Klaassen (2004). Impacts of CO_2-taxes in an economy with niche markets and learning-by-doing. Env Resour Econ. v.28 (3): 367-394

Halvorsen, Bente and Bodil M. Larsen (2001). The flexibility of household electricity demand over time. Resour Energy Econ. v.23 (1): 1-18

Leighty, Wayne and Alan Meier (2011). Accelerated electricity conservation in Juneau, Alaska: A study of household that reduced demand 25%. Energ Policy. v.39: 2299-2309

Maddala, G. S. and Robert P. Trost and Hongyi Li and Frederick Joutz (1997). Estimation of short-run and long-run elasticities of energy demand from panel data using shrinkage estimators. J Bus Econ Stat. v.15 (1): 90-100

Metcalf, Gilbert E. (2007). A proposal for a U.S. carbon tax swap: An equitable tax reform to address global climate change. *Discussion Paper 2007-12, Hamilton Project, Brookings Institute*.

Nakajima, Tadahiro and Shigeyuki Hamori (2010). Change in consumer sensitivity to electricity prices in response to retail deregulation: A panel empirical analysis of the residential demand for electricity in the United States. Energ Policy. v.38 (5): 2470-2476

Nicholson, Walter and Christopher Snyder (2008). Microeconomic theory: Basic principles and extensions (tenth edition). Mason, OH: Thomson South-Western

Olmstead, Sheila M. (2009). Reduced-form versus structural models of water demand under nonlinear prices. J Bus Econ Stat. v.27 (1): 84-94

Poyer, David A. and Martin Williams (1993). Residential energy demand: additional empirical evidence by minority household type. Energ Econ. v.15 (2):93-100

Prasad, Ragshaw (1983). An evaluation of the lifeline-rate structure using total welfare as a measure of efficiency. Resour Energ. v.5 (3): 201-217

Reiss, Peter C. and Matthew W. White (2005). Household electricity demand, revisited. Rev Econ Stud. v.72 (3): 853-883

Reiss, Peter C. and Matthew W. White (2008). What changes energy consumption? Prices and public pressures. J Econ. v.39 (3): 636-663

Shammin, MD Rumi and Clark W. Bullard (2009). Impact of cap-and-trade policies for reducing greenhouse gas emissions on U.S. households. Ecol Econ. v.68 (8-9): 2432-2438

Taylor, LD (1975). The demand for electricity: A survey. Bell J Econ. v.6: 74-110

Appendix: Other Results

Table 13: Regression results of the demand model when controlling for electric heating

Variables	Coefficient	P-Value
After Tax Income	-0.003	0.694
Interaction between Price and Income	0.005	0.941
Average Price	1901.230	0.905
Single Family Home	99.876	0.607
Trailer Home	317.894	0.225
Electric Cooking	635.135	0.080
Electric Water Heating	(dropped)	
Built after 1970	106.772	0.373
Number of Rooms	134.470	0.000*
Age of Respondent	8.100	0.040*
More than Highschool Education	34.804	0.798
Family Size	88.216	0.085
Respondent is married	-102.202	0.456
Respondent is male	-68.011	0.538
Respondent is white	-563.684	0.025*
Respondent is black	-1105.080	0.001*
Electric Stove(s)	-634.624	0.002*
Gas Stove(s)	-162.290	0.691
Microwave(s)	121.403	0.337
Other fuel type Stove(s)	89.977	0.671
Refrigerator(s)	317.955	0.010*
Builtin Dishwasher(s)	72.984	0.644
Freezer(s)	262.791	0.016*
Portable Dishwasher(s)	-369.393	0.248
Gargbage Disposal(s)	29.839	0.816
Clothes Washer(s)	266.932	0.463
Clothes Dryer(s)	-35.356	0.917
TV(s)	68.023	0.237
Sound System(s)	63.592	0.200
Computer(s)	-54.749	0.493
VCR(s)	76.583	0.172
Cooling Degree Days	19.165	0.387
Heating Degree Days	0.213	0.898
Electric Heating	(dropped)	
Window AC Cooling	753.527	0.692
Central AC Cooling	1180.740	0.372
Interaction between Price and Electric Heating	(dropped)	
Interaction between Price and Window AC	-6203.170	0.748
Interaction between Price and Central AC	-12975.300	0.302
Interaction between Cooling Degree Days and Window AC	-8.087	0.946
Interaction between Cooling Degree Days and Central AC	-31.615	0.152
Interaction between Heating Degree Days and Electric Heating	(dropped)	
Interaction between Price and Cooling Degree Days	-170.594	0.389
Interaction between Price and Heating Degree Days	10.561	0.550
Interaction between Price, Cooling Degree Days, and Window AC	98.997	0.946
Interaction between Price, Cooling Degree Days, and Central AC	322.830	0.103
Interaction between Price, Heating Degree Days, and Electric Heating	(dropped)	
Located in Midwest	193.328	0.623
Located in Northeast	(dropped)	
Located in South	690.864	0.048*
Located in West	250.345	0.347
Constant	-1845.480	0.285

Number of Observations = 847
R-sq = .402

* - p-value < .05

Coefficient : magnitude and direction of impact the variable has on the demand for electricity

Table 14: Regression results of the elasticity model when controlling for incomes between $0-30K

Variable	Coefficient	P-Value
Income Elasticity	-0.069	0.175
Price Elasticity	-0.487	0.447
Single Family Home	0.137	0.431
Trailer Home	0.215	0.342
Electric Cooking	0.199	0.308
Electric Water Heating	(dropped)	
Built after 1970	0.295	0.011*
Rooms greater than 6	0.397	0.000*
Respondent older than 65	-0.031	0.751
More than Highschool Education	-0.275	0.040*
Family Size greater than 2	0.170	0.210
Respondent is married	0.148	0.153
Respondent is male	-0.066	0.490
Respondent is white	-0.140	0.472
Respondent is black	-0.273	0.302
Electric Stove(s)	-0.115	0.486
Gas Stove(s)	-0.097	0.608
Microwave(s)	-0.150	0.158
Other fuel type Stove(s)	0.136	0.537
Refrigerator(s)	0.159	0.111
Builtin Dishwasher(s)	-0.060	0.597
Freezer(s)	0.186	0.021*
Portable Dishwasher(s)	-0.214	0.382
Gargbage Disposal(s)	0.007	0.957
Clothes Washer(s)	0.046	0.822
Clothes Dryer(s)	0.166	0.328
TV(s)	0.074	0.133
Sound System(s)	0.107	0.012*
Computer(s)	-0.014	0.789
VCR(s)	0.073	0.224
Cooling Degree Days	-0.001	0.431
Heating Degree Days	-0.000	0.578
Electric Heating	0.220	0.244
Window AC Cooling	0.093	0.569
Central AC Cooling	-0.062	0.682
Interaction between Cooling Degree Days and Window AC	0.001	0.493
Interaction between Cooling Degree Days and Central AC	0.002	0.148
Interaction between Heating Degree Days and Electric Heating	0.001	0.013*
Located in Midwest	0.191	0.485
Located in Northeast	(dropped)	
Located in South	0.259	0.387
Located in West	0.318	0.059
Constant	4.684	0.001*

Number of Observations = 1075

R-sq = .347

* - p-value ‹ .05

Coefficient : magnitude and direction of impact the variable has on the elasticity of demand for electricity

Table 15: Regression results of the elasticity model when controlling for incomes between $30-50K

Variable	Coefficient	P-Value
Income Elasticity	0.345	0.396
Price Elasticity	0.354	0.605
Single Family Home	0.092	0.655
Trailer Home	0.267	0.482
Electric Cooking	0.298	0.276
Electric Water Heating	(dropped)	
Built after 1970	0.171	0.227
Rooms greater than 6	-0.115	0.359
Respondent older than 65	0.267	0.078
More than Highschool Education	0.192	0.143
Family Size greater than 2	0.135	0.384
Respondent is married	0.163	0.267
Respondent is male	-0.021	0.859
Respondent is white	-0.064	0.810
Respondent is black	-0.059	0.893
Electric Stove(s)	-0.051	0.792
Gas Stove(s)	-0.051	0.835
Microwave(s)	0.095	0.495
Other fuel type Stove(s)	-0.128	0.592
Refrigerator(s)	0.096	0.445
Builtin Dishwasher(s)	0.324	0.024*
Freezer(s)	0.504	0.000*
Portable Dishwasher(s)	0.074	0.808
Gargbage Disposal(s)	-0.041	0.757
Clothes Washer(s)	-0.231	0.543
Clothes Dryer(s)	0.287	0.425
TV(s)	0.071	0.170
Sound System(s)	0.043	0.525
Computer(s)	0.048	0.451
VCR(s)	0.030	0.606
Cooling Degree Days	0.002	0.290
Heating Degree Days	0.000	0.249
Electric Heating	0.088	0.695
Window AC Cooling	0.257	0.202
Central AC Cooling	0.025	0.884
Interaction between Cooling Degree Days and Window AC	-0.001	0.585
Interaction between Cooling Degree Days and Central AC	-0.001	0.683
Interaction between Heating Degree Days and Electric Heating	0.001	0.187
Located in Midwest	0.192	0.515
Located in Northeast	(dropped)	
Located in South	0.663	0.042*
Located in West	0.295	0.128
Constant	1.493	0.745

Number of Observations = 859
R-sq = .365

* - p-value < .05

Coefficient : magnitude and direction of impact the variable has on the elasticity of demand for electricity

Table 16: Regression results of the elasticity model when controlling for incomes between $50-75K

Variable	Coefficient	P-Value
Income Elasticity	-0.522	0.176
Price Elasticity	-0.116	0.819
Single Family Home	0.644	0.000*
Trailer Home	0.566	0.039*
Electric Cooking	0.255	0.351
Electric Water Heating	(dropped)	
Built after 1970	0.025	0.788
Rooms greater than 6	0.060	0.474
Respondent older than 65	-0.067	0.696
More than Highschool Education	-0.071	0.462
Family Size greater than 2	0.304	0.001*
Respondent is married	-0.031	0.806
Respondent is male	-0.132	0.137
Respondent is white	-0.151	0.444
Respondent is black	-0.289	0.361
Electric Stove(s)	-0.305	0.010*
Gas Stove(s)	-0.044	0.862
Microwave(s)	-0.053	0.685
Other fuel type Stove(s)	0.256	0.163
Refrigerator(s)	0.027	0.774
Builtin Dishwasher(s)	0.098	0.452
Freezer(s)	0.190	0.011*
Portable Dishwasher(s)	-0.070	0.737
Gargbage Disposal(s)	-0.047	0.633
Clothes Washer(s)	-0.397	0.104
Clothes Dryer(s)	0.510	0.023*
TV(s)	-0.012	0.757
Sound System(s)	0.035	0.456
Computer(s)	-0.046	0.344
VCR(s)	0.051	0.197
Cooling Degree Days	0.000	0.815
Heating Degree Days	0.000	0.037*
Electric Heating	0.360	0.082
Window AC Cooling	-0.475	0.004*
Central AC Cooling	0.039	0.780
Interaction between Cooling Degree Days and Window AC	0.003	0.017*
Interaction between Cooling Degree Days and Central AC	0.002	0.077
Interaction between Heating Degree Days and Electric Heating	0.000	0.267
Located in Midwest	-0.503	0.000*
Located in Northeast	-0.353	0.168
Located in South	(dropped)	
Located in West	-0.276	0.240
Constant	11.258	0.017*

Number of Observations = 853

R-sq = .393

* - p-value < .05

Coefficient : magnitude and direction of impact the variable has on the elasticity of demand for electricity

Table 17: Regression results of the elasticity model when controlling for incomes above $75K

Variable	Coefficient	P-Value
Income Elasticity	0.090	0.544
Price Elasticity	-1.359	0.045*
Single Family Home	0.108	0.662
Trailer Home	-1.984	0.000*
Electric Cooking	0.340	0.201
Electric Water Heating	(dropped)	
Built after 1970	-0.076	0.537
Rooms greater than 6	0.157	0.233
Respondent older than 65	0.057	0.789
More than Highschool Education	-0.293	0.008*
Family Size greater than 2	0.114	0.309
Respondent is married	0.257	0.162
Respondent is male	0.035	0.742
Respondent is white	0.407	0.067
Respondent is black	0.239	0.540
Electric Stove(s)	0.239	0.068
Gas Stove(s)	0.313	0.160
Microwave(s)	0.254	0.098
Other fuel type Stove(s)	0.091	0.546
Refrigerator(s)	-0.212	0.040*
Builtin Dishwasher(s)	0.137	0.529
Freezer(s)	0.135	0.182
Portable Dishwasher(s)	-0.467	0.330
Gargbage Disposal(s)	0.100	0.420
Clothes Washer(s)	0.042	0.890
Clothes Dryer(s)	0.310	0.180
TV(s)	-0.019	0.691
Sound System(s)	0.099	0.028*
Computer(s)	0.076	0.263
VCR(s)	-0.042	0.392
Cooling Degree Days	-0.001	0.475
Heating Degree Days	0.000	0.563
Electric Heating	-0.149	0.517
Window AC Cooling	-0.070	0.804
Central AC Cooling	0.068	0.745
Interaction between Cooling Degree Days and Window AC	0.003	0.246
Interaction between Cooling Degree Days and Central AC	0.001	0.262
Interaction between Heating Degree Days and Electric Heating	0.001	0.029*
Located in Midwest	-0.531	0.001*
Located in Northeast	0.163	0.624
Located in South	(dropped)	
Located in West	0.031	0.912
Constant	0.469	0.856

Number of Observations = 1029

R-sq = .305

* - p-value < .05

Coefficient : magnitude and direction of impact the variable has on the elasticity of demand for electricity