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Does Information Lead to Household Electricity Conservation?

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This paper estimates the effect of information on residential electricity consumption. Household reading expenditure, education level of the household head, and state "green" electricity pricing program participation rate represent the probability that a household has encountered information relating the carbon emission externalities of energy consumption and human-driven climate change. Reading expenditure has a significant negative effect on household electricity consumption. Initial increases in educational attainment increase electricity consumption, but education beyond high school reduces it. The predicted social norm effect of green pricing participation is insignificant.

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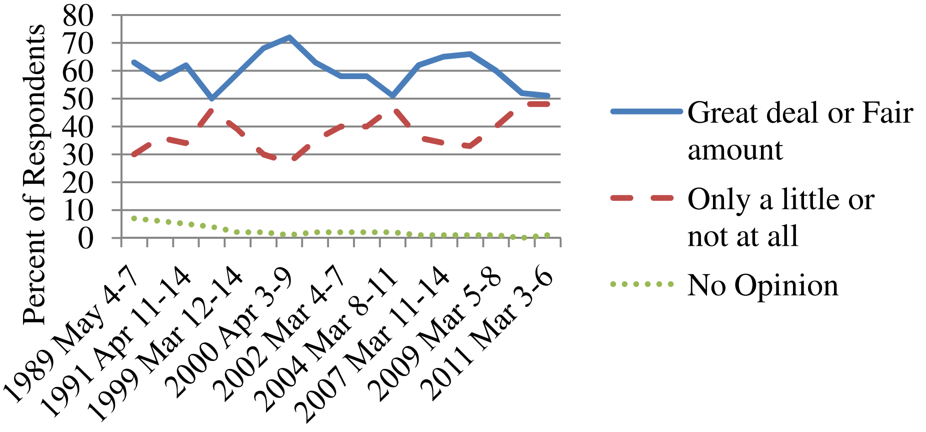
I. Introduction

In the late 1980's, scientists raised the possibility of human-driven climate change. First attempts to publicize findings failed to motivate the public, perhaps because an average worldwide temperature increase of several degrees Celsius did not seem significant to laypeople. Public interest only grew after Congressional hearings and an Environmental Protection Agency report made headlines in the *New York Times*, for example, "The Heat is On: Calculating the Consequences of a Warmer Earth" from 1988. From then on, media was the most prominent source of climate change information. Human-driven atmospheric changes truly captivated public interest during the internationally coordinated effort to solve ozone depletion in the late 1980's (Weart 2008).

Public concern about climate change has been noticeable enough to prompt public opinion polls since the 1990's. Though concern has deviated over time around a relatively constant mean, the majority of Americans express concern about global warming, a testament to the effectiveness of the information from scientists broadcast through the media (see Figure 1). Another significant trend in public opinion polls is the decline in the proportion of respondents who are uninformed or are unsure about the existence of climate change, which indicates that awareness has risen, but some individuals choose not to believe the evidence they have encountered. Yet, according to a Gallup poll in 2008, more than 80 percent of respondents claim that they have made either minor or major changes in their lifestyle to protect the environment, of which 10 percent report conserving electricity.

Figure 1: Gallup Poll Results: How Concerned are you about Climate Change?



In addition to conservation behaviors such as reducing vehicle use, conserving electricity is a common adaptation for households that understand the impacts of greenhouse gas emissions from electricity generation. Yet not all households prioritize energy conservation. In order to reduce greenhouse gas emissions to mitigate consequences of climate change, the effectiveness of information provision must be understood separately from price mechanisms. My paper estimates household electricity demand using the Consumer Expenditure Survey of 2005 to isolate the change in electricity consumption associated with household exposure to climate change information.

In section two I review the economic literature to construct a strong specification model for electricity demand, to develop theory based on previous studies about energy conservation, and the role of information in consumer behavior. I discuss my theory in section three, present my data and regression results in section four, and conclude with the findings and implications of my paper in section five.

II. Literature Review

Nearly all empirical studies on household demand for electricity are based on the models of Houthhakker (1951) and Fisher and Kaysen (1962). Houthakker (1951) calculates elasticities of demand of residential electricity in Great Britain to evaluate the effect of an imposition of two-part tariffs. His study emphasizes the statistical irrelevance of the average price as the independent variable, and instead uses marginal prices of kilowatt-hours as the more significant determinant of electricity consumption.[1] The model also includes household income, the price of a substitute energy good (natural gas), and the ownership of complementary electricity consuming appliances. The study does not attempt to explain the heterogeneity of appliance holdings across households, which Dubin and McFadden (1984) later prove problematic because preferences for electricity use are correlated with appliance choice. Houthakker finds an elasticity of demand coefficient of -0.89 based on household surveys from 1937-1939. The demand for electricity in the present might be expected to be more inelastic, as we have become more dependent on a broader portfolio of electricity-consuming appliances while electricity has decreased as a portion of total expenditure.

Another foundational paper models the distinctions between long term and short term elasticity of demand (Fisher and Kaysen 1962). The main difference between the long and short run is the weaker effect of the substitute energy good price in the short term. Substitution of natural gas for electricity, while holding household services constant, requires a change in the appliance portfolio, which only occurs in the long run. My paper draws only from the short run specification because I use an essentially cross-sectional dataset. A weakness of Fisher and

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[1] Marginal price is the price of consuming the next kilowatt hour, which differs from average price under declining or inclining block rates. Due to data constraints, I will not be able to use marginal price in this analysis. At the time of Houthakker's study, households typically faced declining rate structures. However, utilities in the US today typically chare inclining rate structures. According to Houthakker (1951), the omission biases my results towards from zero because households may be facing a higher marginal price than the average price.

Kaysen is their use of aggregate electricity consumption as the dependent variable, income per capita, and appliance portfolio of a community rather than data from individual households, due to data limitations. Their estimates for price elasticity by state range from 0.14 to -0.94. The wide range might be explained by their use of aggregate dependent and independent variables.

Through the 1970's, the energy crisis brought a resurgence of interest in the elasticity of demand for residential energy consumption to understand the implications of energy price spikes or electricity rationing. Anderson (1973), Houthakker, Verleger, and Sheehan (1974), and Halvorsen (1975) build on the earlier literature. Anderson (1973) acknowledges the weaknesses in the aggregate model of Fisher and Kaysen (1962) and provides a framework to estimate the price elasticities of demand in California and then the United States using household data and the marginal prices of declining rate structures and other factors that vary by state, for example cooling index days and the percent of "all-electric" homes in the state. The estimated elasticities using 1969 data range from -0.58 to -0.77, which is an improvement in precision from Fisher and Kaysen (1962). In addition to the effect of disaggregation, their results might also differ from Houthakker because of the unobserved differences in preferences between Great Britain and the US and several decades of technological change. These studies inform my theoretical approach by supporting the significance of a number of essential control variables, for example heating and cooling days and the price of an energy alternative.

Dubin and McFadden (1984) reveal an essential error in the existing literature of the time. They explain a bias in price elasticity of demand estimates without a correction for the correlation between appliance choice and the error term. The household's unobserved preferences determine both the appliance purchase choice and the intensity of electricity use. For example, a household with strong preferences for cool indoor air is more likely to purchase an air conditioner and to use it heavily in the summer months. Dubin and McFadden suggest three strategies to correct for this error: instrumental variables, a reduced-form method that enters predicted probabilities of appliance purchase directly in the estimation of electricity demand, and the conditional expectation correction method. Without sufficient time or background in these methods, my paper will not control for selectivity bias, but will interpret the results with skepticism knowing the existence of the distortion.

My paper asks whether or not information about climate change induces households to voluntarily reduce electricity consumption. Voluntary conservation results from disutility from each unit of electricity used. Jacobsen et al. (2011) hypothesizes that energy consumption causes disutility, or reduction of satisfaction through consumption, in conserving households, but disutility is absent in households whose behavior is unaffected by messages about climate change. The disutility arises from discomfort and awareness that energy generation produces greenhouse gases that contribute to human-driven climate change. The household avoids disutility by voluntarily participating in a minimum buy-in renewable energy offset program instead of changing the intensity of household energy consumption. This phenomenon is described as a “private provision of a public good” because while the private cost of purchasing energy offsets is significant, the marginal social benefit of the behavior change is negligible.

The paper found that participating households, on net, consumed more with the green electricity program. This result indicates that the cost to the household to buy in to the program was less than the cost of disutility from perceived household contribution to carbon emissions. To the household’s utility function, the cost of switching to renewable sources of energy negates the marginal disutility per kilowatt, and the household consumes according to the market cost of a kilowatt.

Kotchen and Moore (2008) investigate a renewable energy offset program with a green-tariff mechanism, an additional cost for each unit of electricity, rather than voluntary contribution at or above the minimum buy-in amount, as studied by Jacobsen et al (2011). Instead of net increases in electricity consumption, Kotchen and Moore found that households consumed less, but were unable to determine if it was a price effect or a conservation effect. Kotchen and Moore's model and the findings of Jacobsen et al. provide support for the effect of climate change awareness on electricity consumption through the effect of disutility as an internalized cost.

Reiss and White (2008) found evidence of voluntary conservation in households as a result of education campaigns during an energy crisis in California in 2000. The significant response within a short period after a well-orchestrated public appeal campaign, even during a period of price caps, suggests that households change their energy intensity behaviors in response to a change in information in the short run without changes in the appliance portfolio. Literature on the economics of voluntary contributions to a public goods (or reductions of public "bads") can offer support that the results of Reiss and White (2008), Kotchen and Moore (2008), and Jacobsen et al. (2011) are consistent with rational consumer behavior. Andreoni (1990) and Andreoni (1995) frame voluntary charitable contributions as a form of impure altruism because individual utility functions not only consider the tradeoff of private consumption for contributions to a public good, but because individuals also derive utility from the public good.

My paper instead explains the role of information in changing residential electricity demand, as seen in Reiss and White (2008). I assume that households have preferences that cause them to have variable likelihood of exposure to climate change information, and might respond differently to the same information. Instead of the common approach in the literature, I hypothesize that households perceive reductions in electricity usage as preventing contributions to a public bad rather than voluntary reduction as a contribution to a public good. The disutility reduces the overall marginal benefit of electricity, and results in electricity conservation.

The use of education and readership as indicators of information exposure is used by Shimshack et al. (2007) to predict the likelihood that households alter fish consumption in response to mercury advisories. Shimshack et al. uses education based on the hypothesis in Grossman (1972) that an individual improves his/her ability to process information with additional levels of education. Shimshack et al. also assumes that information, if concentrated in news media, will be accessed at a lower acquisition cost for households who read news sources regularly. Their findings demonstrate that information presented in the media affects consumer behavior.

Academic research in psychology suggests that climate change mitigation activities are motivated by economic incentives, moral obligation, social norms, and information, and emphasize that non-price mechanisms can have just as significant an impact as taxes or other economic approaches (Whitmarsh 2009, Allcott and Mullainathan 2010). One study in particular discovered misconceptions about effective climate change mitigation strategies. For instance, recycling was perceived to be effective and thus was the most frequently reported environmental action taken by households (Whitmarsh 2009). The study suggested that improved information could significantly change the impact of intentional environmental behaviors.

Informed by previous studies in electricity estimation, conservation, and information, I next derive for the effect of information in a representative household’s utility function.

III. Theory

In this section, I present a simple model that demonstrates the effect of a change in information on the utility maximization decision in a household. The model most closely relates to household electricity conservation models of Kotchen and Moore (2008) and Jacobsen et al. (2011), but differs specifically because I omit the public good of conservation from the utility function. I assume that individuals within a household have homogenous preferences, the purchase choice of a durable is predetermined, and increases in information have a negative effect on the marginal utility of electricity consumption because the household incurs guilt for perceived contributions to negative externalities through electricity use and carbon emissions. The information parameter δ encompasses factual knowledge of electricity generation externalities and informal social pressures to advertising conservation campaigns, either for environmental reasons or for energy crises response, such as the one described in Reiss and White (2008).

Households choose the level of electricity to consume through appliance durables and derive utility from the household services provided by the electricity consumptive appliances. A representative household maximizes its utility subject to a budget constraint. Utility is a function determined by household services h, all other consumer goods x, and the total disutility associated with the level electricity consumption, E multiplied by the function $d(\delta)$, which is the average disutility per kilowatt hour. Household services are determined by the parameters E, electricity use in kilowatt hours, and by the appliance portfolio they own, D. Household services are not discounted because they represent consumption within one time period.

$$U = U(h(E, D), Ed(\delta), x) \quad \textbf{(1)}$$

Electricity use of the household is determined by:

$$E = E(H, D, C, P_E, P_S, Y) \qquad \textbf{(2)}$$

The endogeniety problem described by Dubin and McFadden (1984) is evident here in Equation (1), because the purchase decision for D is determined by household characteristics vector H, which also is a parameter in the demand for electricity, which is described in Equation (2). The vector H includes characteristics relevant to electricity consumption such as education level, age, and number of household members, energy efficiency, location, and type of household structure, and unobservable preferences. Household utility is also affected by a degree of disutility associated with each unit of electricity. The functional form of $d(\delta)$ is uncertain, but it is reasonable to assume that $d(\delta)$ is never positive and $\frac{\partial U}{\partial \delta}$ is less than zero. A household experiences decreases in marginal utility as they internalize information about negative externalities of electricity consumption, but at a certain threshold of understanding, additional information's effect on utility is diminishing. For the purposes of this model, $d(\delta)$ is exogenous, meaning that the household cannot choose the level of information available to them or how information affects their utility.

Other factors of electricity demand (as seen in equation 2) are climate C, the price of a kilowatt-hour P_E, the price of a substitute for electricity[2] P_S, and household income Y.

The household's optimization problem is defined as:

$$\max_{E,x,\lambda} \Phi = U[\, h(E \mid D), Ed(\delta), x] + \lambda(Y - P_E\, E - P_x\, x) \qquad \textbf{(3)}$$

[2] The literature consistently chooses natural gas prices because natural gas is a close substitute for electricity as an input for household services. See Houthakker (1951), Fisher and Kaysen (1962), Anderson (1973), Houthakker, Verleger, and Sheehan (1974), and Halvorsen (1975).

The budget constraint is income minus the expenditures on electricity and all other goods. The household utility maximization equation (3) is the utility function subjected to the budget constraint, and is characterized by the first order conditions (4a), (4b), and (4c).

$$\frac{\partial \Phi}{\partial E} = \frac{\partial U}{\partial h}\frac{\partial h}{\partial E} + \frac{\partial U}{\partial E} d(\delta) - \lambda P_E = 0 \quad \textbf{(4a)}$$

$$\frac{\partial \Phi}{\partial x} = \frac{\partial U}{\partial x} - \lambda P_x = 0 \quad \textbf{(4b)}$$

$$\frac{\partial \Phi}{\partial \lambda} = Y - P_E E - P_x x = 0 \quad \textbf{(4c)}$$

The first order condition (4a) for the marginal utility of electricity reveals the effect of a change in information to the amount of electricity consumed by the household. To explore the effect of a change in δ, (4a) is rearranged to obtain:

$$\frac{1}{\lambda}\left[\frac{\partial U}{\partial h}\frac{\partial h}{\partial E} + \frac{\partial U}{\partial E} d(\delta)\right] = P_E \quad \textbf{(5)}$$

The first term in brackets represents the change in utility with respect to a change in electricity due to the positive impact of electricity use on the level of household services. The combination of this term with the marginal disutility of electricity, which is the second term in the brackets, represents the marginal benefit in utils of an additional kilowatt hour, which is then converted by the inverse of λ, the marginal utility of income, to dollar units. The right-hand side is the marginal cost in dollars per kilowatt hour. The impact of a change in information increases the magnitude of the marginal disutility with respect to a change in electricity. When there is an increase in information (and $d(\delta)$ becomes a larger negative value), the marginal benefits decrease relative to the marginal cost at the original level of consumption. The household must compensate by reducing the level of electricity consumption to maximize utility.

Though the simple model assumes a representative household, in a more accurate model, each household responds differently to the same level of information. For example, many

American households are skeptical of the existence of negative externalities from fossil fuel consumption (which is the dominant source of generated electricity). Thus, this model assumes the information parameter is internalized. A household with both $d(\delta)$ and $\frac{\partial U}{\partial \delta}$ equal to zero indicates that they have no information or do not internalize information so they do not experience disutility as a result of electricity consumption.

IV. Data

a. Ideal Data

To test this paper's hypothesis, the ideal data would be drawn from a survey of household electricity consumption that includes a quantifiable measurement for a household's exposure to messages about climate changes (which could take the form of current event reading or frequency of watching news coverage on TV) as well as a measurement of the degree to which the household internalizes these messages. For example, this observation would indicate whether the individual is consciously aware of externalities as they utilize household appliances. This measure would ideally combine the extent of accurate knowledge of carbon dioxide emissions and the emotional effect on utility, and the values would be gathered over time and across households to isolate changing prices and changing awareness. In addition these explanatory variables, the survey would include time spent at home, income, education, house characteristics (as they apply to the energy efficiency of the home), average temperature for the month, location of the household, number of appliances owned and the efficiency ratings of each, and the full range of demographic factors, such as number of individuals of the household.

In addition to a measure of environmental consciousness, I would need an indicator of energy intensity preferences to correct selectivity bias of appliances, as well as a way to control for education's role in selectivity bias.

b. Actual Data

Unfortunately, the ideal data is not fully available. Instead, this paper uses the Consumer Expenditure Survey (CEX), a survey performed by the Bureau of Labor Statistics to document trends in American consumption patterns. The 2005 CEX, which includes data for five consecutive quarters beginning with the first quarter of 2005, interviewed households about their expenditures for the current month and the previous three months, as well as a number of household characteristics, including education of household head, income, family structure, housing tenure, appliance holdings, and other data. Information about households was collected although there are no measures beyond square footage, the year the house was built, and number of rooms to describe the household characteristics of energy efficiency. In the case that the household uses air conditioning in the summer months and the insulation is poor, the electric bill will be significantly higher than a household that exhibits the same behavior of using air conditioning in a more efficiently constructed home. More importantly, there is no direct survey question to measure the awareness of climate change.

The five quarters were separate data sets, so they have been appended together so that each household for each quarter appears as a new observation. In the regression analysis, I cluster by household to correct standard errors for correlations in within household electricity consumption across quarters.

I derive kilowatt hours of electricity consumed per quarter from the CEX electricity expenditure data by matching a rolling average by quarter of monthly prices per kilowatt hour by state according to the month that the household was interviewed. I obtain the price data from the Energy Information Administration. Dividing the expenditure by the rolling average provides a rough estimate for the number of kilowatt hours consumed. Electricity expenditure is not a satisfactory dependent variable because of wide variations in average price by state. For instance, two households facing different prices may have the same expenditure, but consume significantly different levels of electricity. The price of a substitute energy good, natural gas, was also taken from the Energy Information Administration and matched to the month that the household was interviewed by rolling average. I gather heating and cooling degree day data by state to control for fluctuations in weather from the National Oceanic and Atmospheric Administration. I match these data to each observation by quarter and by state. Lastly, I obtain the 2005 count of participants in voluntary green pricing programs from the Energy Information Administration, and I derive green pricing participation rates by dividing the number of participants by the state population found from the US Census.

I use reading material expenditure as a proxy for exposure to and awareness of messages about climate change, following the example of Shimshack (2007). If a household has been presented with information about climate change through formal education or from reading published media, the utility maximization decision will occur at a lower level of electricity consumption for a comparable household with less information. Because of education increases information processing, the household head education level is controlled for in the model. Thus, the null hypothesis is that education and readership have no impact on household electricity consumption, whereas the alternative hypothesis is that these two factors will be estimated with negative coefficients. A third proxy for information is the percent of the population who voluntary participate in green pricing programs through their electric utility. I match the participation rate to each household according to state. Green pricing participation is an indication of households making a discrete decision to voluntarily face a higher price to reduce electricity use. The motivation for which might be assumed to be for environmental concerns because of the intentional name “green pricing program”. A higher participation rate within a state increases the likelihood that a household in the sample is affected by a social norm pressure to conserve as described by Hunt and Allcott (2010). Social norms facilitate behavior change because individuals believe that crowds have better information about the benefits of a particular action.

Interaction terms between reading and education levels should return negative coefficients increasing in magnitude with higher levels of education because a greater potential for processing information will amplify the responsiveness of an individual to information about climate change.

I include a series of household characteristics to control for variation in electricity consumption not related to my variables of interest. Dummy variables for region capture unobserved differences in the social norms of electricity usage common to neighboring groups of states. Tenure is a dummy variable which is equal to one when the household owns the residence and is equal to zero when they rent or reside without payment. Whether a household owns the home, whether it is through a mortgage or not, is expected to have a negative impact on electricity consumption because householders would have more incentive to invest in insulation or other electricity saving methods as opposed to renters. I include dummy variables for the population of the household’s city because access to substitute energy goods differs between rural and urban locations (Labandeira et al. 2005). For this sample, I include five indicator dummy variables for the population size of the city where the household is located.[3] Urban households also may be more likely to use electricity less intensively compared to rural dwellers because of non-random differences in residence structure, income, education, or appliance portfolio.

Number of family members and number of rooms are expected to have a positive effect on electricity consumption. It is also important to include a term for the number of rooms squared. The squared term for rooms captures increasing costs to heat or cool an additional room until the ratio of outside surface area to volume decreases to the point of decreasing marginal cost for each additional room. Age is also supplemented by a squared term to describe the trajectory of appliance accumulation with age, and then a decrease in use intensity as children leave and household heads age. I expect a generational component to climate change awareness. Messages about human-driven climate change have been met with much skepticism in older people while generally accepted more readily by the younger generation, so there might be a positive linear trend between electricity consumption and age. I also included the age of the building to proxy for energy efficiency, expecting that newer homes would be more energy efficient

c. Summary Statistics

To assess the basic characteristics of my sample before the estimation model, below I present summary statistics (Table 1). Out of the total 54633 observations in the dataset, 29729 are usable. I exclude households that reported negative total expenditures, in addition to households that reported zero expenditure on electricity for the time period because their

[3] The categorical variable designed by the CEX includes an indicator for households in cities with the following ranges of population size: More than 4 million, 1.20-4 million, 0.33-1.19 million, 125-329.9 thousand, and less than 125,000.

response to price and disutility are unobservable and irrelevant to the hypothesis. Also, between four thousand and five thousand observations do not report the household's state. One model also tests the robustness of the results when excluding all states to which observations were re-coded. In this sample, kilowatt hours consumed has a large standard deviation. For example, the most consumption by one household was 38,249 kilowatt hours, compared to the least, or 5.98 kilowatt hours. The large variation provides an opportunity to explain variation in consumption patterns in conjunction with other information reported by the consumer unit.

The sample represents a varied composition of households according to the categorical variable of household head's education level (see the dummy variable means for education levels in Table 1). The Bureau of Labor Statistics reports of educational attainment from the year 2005 lend credibility to the representative distribution of the sample compared to the national distribution of education.

However, the sample is biased towards urban households. The US Census defines urban areas as cities with more than 50,000 residents, and that 80 percent of the United States population lived in an urban area in the decade between 2000 and 2010. However, more than 90 percent of my sample lives in cities greater than 100,000, so my sample over-represents households in urban areas.

Total reported expenditure was used rather than the household's income because expenditure better represents the household's budget constraint. A considerable number of observations in the complete dataset report zero or negative income and still have positive expenditures in reading materials, in electricity, and overall. Presumably the contradiction occurs for individuals receiving welfare, using savings or some source of income not reported in the Survey. Slesnick (2001) argues that income is a less than ideal measure of household consumption and welfare, especially in the short run. For a narrow time period, households may appear to have vastly different standards of living if income is the indicator, but they might have comparable levels of consumption if they are merely at different stages in the life cycle and smoothing consumption.

In summary, a full analysis controlling for the crucial variables such as household demographics and characteristics, education, and total expenditure will return a negative coefficient for electricity consumption for the variable of readership expenditure and possibly for education.

V. Results

a. Estimation Equation

The predictions of the theoretical model are tested by an empirical equation that explains variation in electricity consumption by reading expenditure. Reading expenditure, controlling for education level, increases the likelihood that a household is exposed to information about the externalities of electricity production. Education could indicate a greater sensitivity to climate change information because higher levels of education would improve an individual's ability to process information, and result in a greater degree of internalization of climate change messages in the media (Shimshack 2007, Grossman 1972). A third explanatory variable, the percentage of the state population who voluntarily participates in green electricity pricing programs, is an indication of the social norms within a state with regard to conservation. The resulting ordinary least squares estimation specification is Equation 6.

$$ln(kilowatt\ hours) = \beta_0 + \beta_1 ln(kilowatt\ hour\ price) + \beta_2\ ln(total\ expenditure) + \beta_3\ ln(natural\ gas\ price) + \beta_4\ ln(reading\ expenditure) + \beta_5\ E(vector\ of\ education\ variables) + \beta_6\ heating\ degree\ days + \beta_7\ cooling\ degree\ days + \beta_8\ housing\ tenure + \beta_9\ age\ of\ building + \beta_{10}\ number\ of\ rooms + \beta_{11}\ number\ of\ rooms\ squared + \beta_{12}\ family\ size + \beta_{13}\ age\ of\ household\ head + \beta_{14}\ age\ squared + \beta_{15}\ vector\ of\ community\ size\ indicators + \beta_{16}\ vector\ of\ region\ indicators + \beta_{17}\ vector\ of\ electric\ appliance\ indicators + \beta_{18}\ \varepsilon \qquad \textbf{(6)}$$

Several models are presented to assess the relevance of a number of potential factors for residential electricity consumption that must be controlled for to isolate the predicted effect of the three main explanatory variables. I estimate a log-log relationship between the dependent variable (kilowatt hours) and the independent variables (electricity price, total expenditure, price of natural gas, and reading expenditure).[4]

b. Regression Results and Discussion

My first model uses the basic specification equation to estimate the effect of reading expenditure on kilowatt hours, controlling for education level of the household head. Model 2 includes interaction terms between each level of education dummy variable and reading, plus and interaction term between reading and household head age. I add green pricing participation rate to proxy social norm effects of conservation in my third model. In the last two models, 4 and 5, I introduce a change in specification by incorporating state and quarter fixed effects instead of heating and cooling degree days and also a model that drops any state that has been re-coded or a state to which re-coded states have been assigned.[5] I remove temperature days and regions from

[4] I performed a Box-Cox regression for each of the variables, and the log likelihood coefficient theta is significant to the 0.001 level for each.

[5] The recorded value for state is recoded for some households for privacy reasons. All states that were re-coded from or to are dropped in Model 5 to eliminate any possibility of incorrect matching of kilowatt hour or natural gas prices.

Models 4 and 5 because, by definition, these two variables are perfectly correlated with the state dummy variables and would otherwise be redundant. State-fixed effects capture state-specific unobservable cultural preferences for electricity use that are omitted in the first three models.

In each of the five models I regress while clustering for the same household, rather than using each reported quarter as a separate observation, to account for correlation across observations of the same household. The entire dataset has 17,244 households, but my usable subsample includes 9,520 households and 29,729 total observations.

Each of the control variables discussed above were consistently significant and of the expected sign, with the exception of tenure. The estimate for tenure was positive, which indicated that homeowners tend to consume more electricity than renters. A potential explanation could be that the predicted effect of a homeowner's financial incentive to invest in energy efficiency was overwhelmed by the tendency for owned residences having more rooms than rented apartments.[6] The sign of the coefficient for the age of the building was inconsistent between positive and negative and never significant. Perhaps the state of repair, rather than the age of the house, better determines the energy efficiency.

The population size indicator variables exhibit a pattern in which households in cities of more than 4 million or 0.33-1.19 million on average consume 3 percent fewer kilowatt hours than the reference population size indicator (below 125 thousand).[7] A simple multi-collinearity test showed a tendency for households in cities of than 4 million or 0.33-1.19 million to be less likely to own their home and more likely to have fewer rooms. However, the population size indicators all have weak, if any, significance.

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[6] According to a multicollinearity test of the sample.

[7] The calculation for all semi-log percentage estimates is given by $g^* = e^{c-V/2} - 1$ where c is the estimated coefficient and V is the estimated variance of c (Kennedy 1981, Anderson and West 2006).

Models without state fixed effects are estimated with indicators for region and heating and cooling degree days. While the Northeast is insignificant, potentially because of the wide variation in household characteristics across a densely populated region, while the positive coefficient on South is highly significant, presumably because of the social norm of intensely using air conditioning in hot summers. The coefficient on South suggests that, on average, Southern households consume 40 percent more electricity than Western households, which is the reference region, controlling for all other variables in the model.

Across the first three models, the price elasticity of demand is -0.40 or -0.41, which is within the range for short term residential demand found by Houthakker, Verleger, and Sheehan (1974), but slightly more inelastic than the short run estimates Fisher and Kaysen (1962), who include fewer household control variables, for instance, the number of rooms. My model explains variation in household electricity use more precisely with the addition of household variables, and reveals that price elasticity of demand for electricity is even more inelastic than the early literature's estimation. After controlling for selection bias, Dubin and McFadden (1984) estimate that price elasticity of residential demand for electricity is within a range of -0.197 to -0.310, depending on the household appliance portfolio and type of selection bias correction, which is even more inelastic than my estimation. The addition of state fixed effects changes the price elasticity to -0.37, and the last model estimated price elasticity to be -0.78. If the number of recoded observations were significant, the dropping of all recoded states might have eliminated incorrectly matched prices and the model could be estimating a coefficient closer to the true value. Because of the need to drop heating and cooling degree days because they correspond directly to state dummy variables, I still control for general seasonality of electricity use by introducing quarter fixed effects.

The cross price elasticity of the substitute across the models ranges between 0.11 and 0.41, becoming more responsive with state fixed effects and state drops, like the own price elasticity. The relative inelasticity reflects the imperfect substitutability of natural gas and electricity in the short run, for example, the capital cost of replacing an electric heating system for a natural gas system, or the problem of access for some households. The income elasticity (0.21 - 0.23) is positive and very inelastic, which indicates that electricity is a normal good and a necessity.

Model 1 estimates the effect of all controls and the main explanatory variable log of reading materials expenditure. The significant but small coefficient on the log of reading materials expenditure can be interpreted as the percentage change of electricity consumption with a one percent increase in reading expenditure. Thus, Model 1 suggests that an increase in reading expenditure by one percent would cause a household to change some electricity consumption behavior to reduce kilowatt hours by 0.6 percent, and the relationship significant at the 0.05 level.

The direct negative effect of reading expenditure on electricity consumption is diminished in magnitude and significance by the addition of interaction terms or state fixed effects, but Models 2 and 3 still estimate a negative coefficient for log of reading. With state recoding drops, responsiveness of electricity use to reading expenditure is 1.1 percent with an increase in reading material expenditure by one percent, which is the greatest estimates response in all models. Again, if the elimination of incorrect state matches is significant and brings coefficient estimates closer to the true value, Model 5 supports my alternative hypothesis the most.

Though only the some high school and high school completion education dummy variables are significant at the 0.05 level in Models 1 through 4, a pattern of declining average electricity consumption relative to the reference level (no formal schooling and no high school) emerges. An increase in income with higher education levels, and therefore an increase in the appliance portfolio, might explain the greater average consumption of all households except graduate degree holders compared to the reference level.

In the second model, all but one of the interaction terms between reading expenditure and education levels are negative, which supports my prediction that education increases an individual's ability to process information, though none are significant. A negative coefficient for this interaction indicates that an increased education level has an additional negative effect on kilowatt hours consumed associated with reading expenditure. An additional one percent increase in reading expenditure for high school or college graduates are associated with a 2.5 or 1.8 percent decrease kilowatt hours, respectively. The coefficient on the interaction term for advanced degree is positive, insignificant, and is smaller in magnitude than high school and undergraduate. Perhaps advanced degree holders have less sensitivity to additional information if information has a diminishing effect on disutility.

In all models, kilowatt hours increases slightly with the age of the household head, but I added an age squared term to capture a lifecycle trajectory, where energy use peaks mid-life because of a larger family, and decreases as activity in the house tapers off with age. The interaction term between reading and age could differentiate individuals of an older generation who are frequent readers from the rest of their more conservative peers in terms of conservation internalization. However, the coefficient is positive, which would indicate that older readers consume less than 0.1 percent more electricity with each one percent increase in reading material expenditure. This result, however, is statistically zero.

The third model introduces the green pricing participation variable, which has an unexpected positive coefficient and is also insignificant.[8] The coefficient can be interpreted as the average change in electricity consumption in households in response to an increase in one percent green pricing participation in the same state. Preliminary analyses found it to be strongly significant and negative before the clustering of observations by household, so the inflated significance must have originated with strong correlations within households across quarters, and the addition of the age of the building changed its sign. The result could be a similar response to the increase in net electricity consumption observed by Jacobsen et al. (2011).

Across all models, the own price elasticity, income elasticity, and effect of increased percent of reading expenditure maintained the same magnitude and significance. The results strongly support a negative effect of reading expenditure on electricity consumption, and weakly support a decline in electricity use as education level of the household head rises. However, I cannot conclude that green pricing participation rate by state has a significant correlation with electricity use among households of that state. A particularly interesting result that interactions between reading material expenditure and education levels are increasingly negative as education rose because higher levels of education, as Grossman (1972) hypothesized, increase an individual's ability to process information, so the sensitivity to climate change messages would increase in addition to greater likelihood of encountering information about the greenhouse gas effect.

Though the results of my study do support my hypothesis that information induces households to conserve, the magnitude of this effect is still dwarfed by price responsiveness.

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[8] An F-test found the contribution of green pricing participation to the model to be meaningless.

Take for example the average household that spends $332 per quarter on electricity, and $52 on reading materials. If the household increased their expenditure of reading materials by one dollar, they would decrease their kilowatt hour use by 0.4, whereas if the same amount of electricity cost one dollar more, they would conserve 4.4 kilowatt hours. Though the average household response to price is 10 times the response to reading expenditure of the same dollar amount, compared to the average electricity consumption use per quarter of 3590 kilowatt hours, neither option seems likely to change behavior greatly. For policy concerns, price responsiveness might be more effective, unless more targeted and abundant information could increase the likelihood of behavior change.

VI. Caveats

The significance of reading material expenditure as an explanatory variable for electricity consumption seems to support the theoretical framework of this paper. However, this conclusion must be considered in light of a number of caveats in the case that the variable is significant through a different mechanism than through disutility from knowledge of negative externalities of electricity consumption. As stated previously, the measure of income is quarterly consumption, not annual income. The Consumer Expenditure Survey does not specify what kind of published reading material is reported, so there is no guarantee that the household purchases media that presents current events, that the household members encounter news stories about climate change, or that the household members even pay attention to media coverage of climate change.

Furthermore, exposure also does not necessarily lead to behavior change. Awareness may only lead to willful ignorance as has been the case in the United States because of how politically polarized the issue of climate change has become (Weart 2008).

A major limitation of my specification model is that I do not correct for selectivity bias. Ordinary least squared analysis is biased in this case because the error term is effectively a function of appliance choice. The household preferences that precipitate a particular electronic appliance purchase are also likely to dictate a higher intensity of electricity use through that appliance, for example, a room air conditioner. I identify a number of endogeniety problems here. Appliance choice can be determined by unobservable preferences, income, education, and information. I include dummy variables for type of heating and water heating systems as a rough correction.

Appliance selectivity bias may also occur when an individual is more likely to estimate paybacks from more efficient appliances, for example, if they have a higher level of education. Household income can also affect electric appliance decisions because households with greater income may be able to spend more for appliances that last longer or are more energy efficient.

VII. Conclusions

In this paper I estimate the effect of three explanatory variables that would support the hypothesis that disutility occurs in households that have internalized information about the connection between electricity consumption externalities and human-driven climate change. A household's reading materials expenditure, which represents the probability that a household would encounter news media about climate change, has a consistently negative effect on household kilowatt hour consumption. Increases in education level, though not all indicator variables were significant, tend to be associated with an initial increase in electricity consumption with respect to the reference level of no formal schooling. Compared to the reference level of no high school education, average electricity use drops as education rises.

Additional educational attainment represents an increase in an individual's ability to process, and can also represent unobservable preferences of an individual to seek information. Interaction terms with education level and reading suggest that individuals are increasingly sensitive to information with higher levels of education, but diminishing effects of information appear at the graduate degree level. Lastly, "green" electricity pricing program participation rates per capita among states, which would indicate a social norm pressure to reduce electricity consumption, was insignificant.

My theoretical framework is supported at least by the significance of the reading expenditure variable, which proxies the level of information available to the household, and the negative effects of education on average household electricity use. My results suggest that households perceive the negative externalities electricity consumption as a contribution to a public "bad", and derive disutility from electricity consumption. A good associated with a perceived public good or bad is different from goods that carry potential private costs because individuals can't accurate measure, and therefore usually overestimate, their contribution to the public good or bad.

However, the results of my model imply that price changes still have the greater negative effect on electricity consumption behavior than information. If the goal is to reduce residential energy consumption, an increase in price change will be effective, but the incidence will be highly regressive because the income elasticity is near zero. However, in cases such as the California energy crisis in 2001, as analyzed by Reiss and White (2008), education campaigns do have an effect if the information is available and targeted.

These results are subject to several limitations. Though the proxy coefficients identified for this analysis were the expected sign according to theory and significant, the connection is tenuous. An increase in expenditure in reading materials is no guarantee that the household will encounter or internalize messages promoting carbon neutrality. The negative coefficient on both main explanatory variables may be the cause of unobserved effects of education or readership. Education may cause an individual to value substitute goods to household services provided, or to budget more consciously to save money on electricity. Though the estimation of education dummy variables indicates that the household electricity consumption generally decreases with higher levels of education, the percentage change in kilowatt hour for each level of education is negligible realistically though the model's coefficient is significant.

A final limitation is that my analysis does not correct for selectivity bias as described by Dubin and McFadden (1984) and Train (1986). Ordinary least squares attributes variation in the sample caused by household preferences to the coefficient of price. Without Dubin and McFadden's correction, appliance choice selectivity bias may have caused the price elasticity estimates to be greater in magnitude than the true coefficient. The approach within my capability to correct this error would be to use a two-stage approach. I would first estimate the probability of a household choosing electric water heating, space heating, or other appliances using the instrumental variable of when the house was built. Though this variable is imperfect because the age of a residence will be negatively correlated with its energy efficiency, the era the house was constructed might be a high predictor of whether the prevailing heating technology or availability was natural gas or electric. Train (1986) elaborates on similar selectivity bias found in the use of automobiles.

Future research for this topic would need to correct for selectivity bias by using instrumental exogenous variables to predict the choice of electric central heating and electric water heating. Potential instrumental variables could include the capital cost of electric or natural gas systems or the year the residence was built. Further analysis could also identify a more fitting explanatory variable to accurately describe the pervasiveness of energy conservation by state, or could use a different household-level data set specific to electricity use and habits closely related to environmental awareness such as recycling. Also, this analysis could be replicated using additional years of the CEX to create an opportunity to follow variation in the diffusion of carbon neutrality messages in popular media over time. An exogenous variable of charitable contributions may also be a helpful factor to indicate households that may experience disutility from knowledge of externalities that do not directly inflict a cost. Lastly, interaction terms between population size indicator variables and the explanatory variables might be able to find a relationship supporting the pressures of social norms on household energy use.

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IX. Tables

Table 1: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Kilowatt Hours	29729	3592.83	2527.71	5.98	38249.04
Price per Kilowatt (cents)	29729	9.68	2.54	5.86	22.54
Price of Natural Gas (\$ per ft^3 x 10^3)	29729	14.13	4.07	5.08	33.07
Total Expenditure (\$)	29729	14498.92	12443.76	82.45	266148.90
Reading Expenditure (\$)	29729	52.85	144.04	0	8193
No High School (%)	29729	0.03	0.17	-	-
Some High School (%)	29729	0.06	0.25	-	-
High School (%)	29729	0.21	0.41	-	-
College Degree (%)	29729	0.54	0.50	-	-
Graduate Degree (%)	29729	0.16	0.36	-	-
Green Pricing Participants	29729	29217.47	61998.14	0	360398
Green Pricing Participation Rate	29729	0.003	0.006	0	0.03
Age of Building (years)	29729	37.54	29.91	1	286
Age of Household Head	29729	53.03	16.01	16	86
Cooling Degree Days	29729	340.22	435.16	0	1876
Heating Degree Days	29729	997.05	1002.39	0	4024
Family Size	29729	2.58	1.43	1	12
Northeast (%)	29729	0.15	0.36	-	-
Midwest (%)	29729	0.22	0.42	-	-
South (%)	29729	0.36	0.48	-	-
West (%)	29729	0.27	0.44	-	-
Population > 4 million (%)	29729	0.31	0.46	-	-
Population 1.20-4 million (%)	29729	0.27	0.44	-	-
Population 0.33-1.19 million (%)	29729	0.18	0.39	-	-
Population 125-329.9 thousand (%)	29729	0.16	0.36	-	-
Population < 125 thousand (%)	29729	0.08	0.28	-	-
Tenure (%)	29729	0.25	0.43	-	-
Electric Heating (%)	29729	0.32	0.47	-	-
Electric Water Heating (%)	29729	0.86	0.35	-	-
Number of Rooms	29729	6.62	2.17	1	25

Table 3: Regression Results

Variable	1	2	3	4[C]	5[CR]
Log of Price	-0.41**	-0.40**	-0.41**	-0.37**	-0.78**
	(-9.62)	(-9.6)	(-9.6)	(-2.66)	(-4.66)
Log of Total Expenditure	0.23**	0.23**	0.23	0.23**	0.21**
	(16.31)	(16.35)	(16.31)	(17.29)	(11.75)
Log of Natural Gas Price	0.12**	0.11**	0.13**	0.13**	0.41**
	(4.68)	(4.65)	(4.68)	(5.91)	(6.23)
Log of Reading Exp.	-0.006*	-0.001	-0.006*	-0.003	-0.01*
	(-1.99)	(-0.03)	(-1.99)	(-1.04)	(-2.51)
Some High School	0.10*	0.10*	0.10*	0.11*	-0.0007
	(2.25)	(2.14)	(2.25)	(2.11)	(-0.01)
High School Grad	0.08*	0.25*	0.08*	0.08*	0.02
	(2.14)	(2.35)	(2.14)	(2.11)	(0.33)
College	0.01	0.02	0.01	0.02	-0.04
	(0.34)	(0.52)	(0.34)	(0.48)	(-0.69)
Graduate School	-0.04	-0.10	-0.04	-0.04	-0.09
	(-0.97)	(-1.87)	(-0.97)	(-0.95)	(-1.44)
Some High School*Read	-	-0.005	-	-	-
		(-0.22)			
High School Grad*Read	-	-0.01	-	-	-
		(-0.74)			
College*Read	-	-0.008	-	-	-
		(-0.41)			
Graduate School*Read	-	0.01	-	-	-
		(0.56)			
Green Pricing	-	-	0.28	-	-
			(0.22)		
Age	0.02**	0.02**	0.02**	0.02**	0.02**
	(6.73)	(6.71)	(6.73)	(6.79)	(5.38)
Age Squared	-0.0001**	-0.0001**	-0.0001**	-0.0001**	-0.02**
	(-5.52)	(-5.71)	(-5.52)	(-5.59)	(-4.67)
Age * Read	-	0.0004	-	-	-
		(1.86)			
Cooling Degree Days	4×10^{-5}*	4×10^{-5}*	4×10^{-5}*	-	-
	(2.43)	(2.42)	(2.44)		
Heating Degree Days	2×10^{-5}**	2×10^{-5}**	2×10^{-5}**	-	-
	(2.98)	(2.91)	(2.95)		
Family Size	0.09**	0.09**	0.09**	0.09**	0.09**
	(17.27)	(17.29)	(17.28)	(17.29)	(12.74)
Northeast	-0.002	-0.0002	-0.002	-	-
	(-0.08)	(-0.01)	(-0.05)		
Midwest	0.14**	0.14**	0.14**	-	-
	(5.44)	(5.58)	(5.45)		
South	0.35**	0.35**	0.35**	-	-
	(15.86)	(16.06)	(15.83)		
City Size 1	-0.03	-0.03	-0.03	-0.04	-0.0002
	(-0.96)	(-0.99)	(-0.93)	(-1.16)	(0.00)
City Size 2	0.02	0.02	0.02	0.02	0.07
	(0.92)	(0.92)	(0.89)	(0.43)	(1.30)
City Size 3	-0.03	-0.03	-0.03	-0.02	-0.005
	(-0.97)	(-0.95)	(-0.96)	(-0.57)	(-0.08)
City Size 4	0.03	0.03	0.03	0.04	0.08
	(1.23)	(1.21)	(1.25)	(0.99)	(1.23)
Electric Heating	0.19**	0.18	0.19**	0.18**	0.20**
	(8.59)	(9.38)	(8.55)	(7.83)	(4.99)
Electric Water Heating	0.18**	0.19**	0.18**	0.22**	0.22**
	(8.65)	(8.53)	(8.6)	(10.66)	(6.98)
Tenure	0.19**	0.20**	0.19**	0.20**	0.18**
	(8.74)	(8.80)	(8.74)	(8.89)	(6.18)
Number of Rooms	0.12**	0.12**	0.12**	0.11**	0.11**
	(7.77)	(7.88)	(7.77)	(7.31)	(6.14)
Rooms Squared	-0.004**	-0.004**	-0.004**	-0.003**	-0.003**
	(-3.87)	(-3.95)	(-3.87)	(-3.38)	(-3.03)
Age of Building	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-6}	-0.0002
	(0.28)	(0.25)	(0.28)	(0.03)	(-0.58)
Constant	0.02	-0.07	0.02	-0.34	0.68
	(0.12)	(-0.38)	(0.10)	(-1.07)	(1.71)
Observations	29729	29729	29729	29729	29729
Adjusted R^2	0.3971	0.3979	0.3971	0.4217	0.4195

The dependent variable is log kilowatt hours for the quarter.
In parentheses are t-values.
The omitted categories are no high school, region West, and City Size 5.
* less than 0.05 p-value.
** less than 0.01 p-value.
[C] Model controls for fixed effects by state and quarter, coefficients not listed.
[R] Model drops recoded state data points.