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ABSTRACT

We use detailed microeconomic data to investigate why aggregate residential electricity consumption in California has been flat since 1980. Using unique micro data, we document the role that household demographics and ideology play in determining electricity demand. We show that building codes have been effective for homes built after 1983. We find that houses built in the 1970s and early 1980s were energy inefficient relative to houses built before 1960 because the price of electricity at the time of construction was low. Employing our regression estimates, we construct an aggregate residential electricity consumption time series index from 1980 to 2006. We show that certain micro determinants of household electricity consumption such as the phase in of building codes explain California's flat consumption while other factors (such as rising incomes and increased new home sizes) go in the opposite direction. Because homes are long-lived durables, we have not yet seen the full impact of building codes on California's electricity consumption.

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California's electricity use per capita has been almost flat from 1973 to the present whereas that of the U.S. has increased by 50 percent. Explanations for this divergence, called the Rosenfeld curve, have focused on California's energy policies, in particular its increasingly strict building and appliance codes, as well as its milder climate, household demographic trends, and its higher energy and land prices which have made its homes smaller and may have driven some energy intensive heavy industries out of the state (Charles 2009).

The residential sector consumes roughly 34% of California's electricity. Between 1970 and 2007 residential retail electricity sales per housing unit increased by 60 percent for the nation but by only 24 percent for California. Since 1980 residential consumption has been flat (Gorin and Pisor 2007). Underlying the flat macro trend average are the individual purchase decisions of millions of heterogeneous households. At any point in time, there is large variation across households in electricity purchases, but this variation is stable over time. Residential monthly electricity sales data from a California county show that between 2001 and 2008 the ratio of the 90th to the 10th percentile is between 6 and 7 in any calendar year.

This paper uses several unique data sets to examine cross-sectional and temporal variation in household electricity consumption. Our study contributes to a growing literature on residential electricity demand (Aroonruengsawan and Auffhammer 2009; Borenstein 2009; Reiss and White 2005, 2008). Similar to recent studies, we work with a very large residential panel data base that provides monthly electricity purchases for every home in a California county over the years 2000 to 2009. Unlike the recent literature we also have information on the home's physical characteristics, the demographic and socioeconomic characteristics of the household living in the home, own and neighborhood ideology, and information about the attributes of the community the home is in. We use these data to investigate why households differ with respect to their electricity purchases at a point in time and over time.

We find that building codes, which were first instituted in 1978, lower the electricity efficiency of post-code relative to pre-code dwellings after 1983 but not before. We argue that houses built in the 1970s and early 1980s were energy inefficient because the price of electricity was low. Although household electricity purchases are not very responsive to contemporaneous prices, the price of electricity at the time the house was built is negatively correlated with current energy consumption. We also document how electricity consumption depends on liberal/environmentalist ideology, characteristics of the household such as income and number of persons, and characteristics of the residence such as size.

We use our regression estimates to construct an aggregate residential electricity consumption time series index. This index enables us to decompose the residential sector's total change in electricity consumption into several key subcategories including changes over time in the vintages of the building stock, in household demographics, in the size of homes, and in the location of the population. [1] Employing data from 1980 to 2006, we use our decomposition to document countervailing macro trends. We show that while the increase in household incomes and in the square footage of new homes both predict rising average electricity consumption, the phase in of building codes partially offsets these effects. The average home is becoming more energy efficient as new homes are built under more stringent codes and homes built during the 1970s and early 1980s begin to represent a smaller share of the overall housing stock. We predict that this trend will continue.

Empirical Framework

[1] Sudarshan and Sweeney (2008) explain the Rosenfeld curve by employing a macro shift share approach in which they ask how much of the overall difference between California and the rest of the nation can be explained by the composition of California households, urbanization, industry composition, structure floor space, fuel type used, and climate.

Within a household production framework, a household values electricity as an input in producing comfort (e.g. indoor temperature) and leisure and household production activities . A household's electricity consumption depends on three choices: 1) the choice of a specific home that differs along dimensions such as size, vintage, and presence of a pool; 2) the choice of appliances and renovations made to the structure; and, 3) utilization of appliances for leisure and household activities, indoor temperature control and illumination.

A house is a long-lasting durable. At its birth, building codes and decisions made by the developer affect the home's energy efficiency. A developer's decisions depend on current building codes, technology, and energy prices.[2] Houses built during years of low electricity prices could be less energy efficient either because consumers demand less efficient houses or because during times of high housing demand the use of less skilled labor leads to poorer construction.

When a household first moves into a home, it may make changes to the home such as updating durable appliances. If energy efficiency is not capitalized into the resale price of homes, then home owners with the longest expected future tenure in the home have the greatest incentive to invest in new energy efficient durables. Once these durables are installed, the household faces temperature shocks and chooses durables depending on its demographics, income, and time spent at home.

A household's total monthly electricity purchases depend in part on household demographics and time use at a given point in time and a whole collection of past actions (such as durables choices and decisions about the construction of the home) that are only partially observed by the econometrician. We therefore focus on estimating reduced form

[2] Treating energy as an input into the price of housing services, Quigley (1984) shows that an increase in energy prices leads to a decline in the demand for housing and a decline in the demand for energy inputs, including residential electricity demand.

household/month electricity consumption regressions as a function of household income and demographic characteristics, electricity rates, year built, and proxies for household ideology. All else equal, we posit that environmentalist households will consume less electricity.[3] We focus on homeowners because we can observe neither landlord characteristics nor the contractual agreement between the landlord and tenant (Levinson and Niemann 2004).

We investigate the role of building codes and prices at the time the home was built in determining household monthly electricity consumption. We proxy for building codes using vintage year dummies. These dummies proxy not just for building codes, but also for the energy efficiency of major appliances and general construction standards. As seen in Table 1, energy efficiency requirements for California homes have become stricter since the introduction of energy efficiency standards for residential buildings in 1978. Standards for appliances (not shown) have also become stricter.[4] Rosenfeld (2008) argues that per capita electricity sales in California would have been 14 percent higher without California standards and programs. Table 1 also shows that in a survey of households in our county, those living in homes built in the 1970s have older furnaces and AC systems than those living in older homes. An increased prevalence of furnaces and AC systems with ducts also might reduce the energy efficiency of homes built in the 1970s relative to earlier years. Finally, because real electricity prices in

[3] Kotchen and Moore (2007), and Kahn (2007), Kahn and Morris (2009), Kahn and Vaughn (2009) have documented that environmentalists exhibit "greener" day to day consumption choices than the average person. Kotchen and Moore (2007) find that in Michigan environmentalists consume less electricity than observationally similar people. Kahn documents that environmentalists are more likely to have a smaller carbon footprint (based on driving, vehicles owned, and their home's physical attributes) than the average person. One possible explanation for these facts is that environmentalists gain pleasure from engaging in "voluntary restraint".

[4] Energy efficiency codes changed for refrigerators in 1978, 1977, 1987, 1992, 2001; for air-conditioners in 1978, 1979, 1981, 1984, 1988, 1991, 1992, 1993, 1995, and 2006; for clothes washers in 1994, 2004, and 2007; for electric furnaces and boilers in 2008 and for small water heaters in 2004 but also in earlier years (see Nadel 2002 and Residential Compliance Manuals from 1978 to the present). See http://www.energy.ca.gov/2007publications/CEC-400-2007-017/CEC-400-2007-017-45DAY.PDF

California were falling in the 1960s and 1970s and only began to rise in the 1980s, we would expect that homes built in the 1970s would be less energy efficient than earlier and later homes.

Our data, described in detail in the next section, come from a California utility which serves an entire county and a small part of another. Compared to the nation as a whole, this county has the same proportion of college graduates (24 percent in the nation versus 25 percent in this county) and the same proportion of residents above age 64 (12 percent in the nation versus 11 percent in this county), but its population has a smaller share of whites (76 percent in the nation versus 66 percent in this county).

The utility did not institute large price increases in the years for which we have data (2000-2008). In 2001 the utility increased its pricing tiers from two to three (see Table 2 for 2008 tier pricing). There were rate changes in 2001 (coincident with a mass media campaign and therefore unidentifiable), 2005, and 2008, but electricity purchases were remarkably consistent across quantiles (see Table 3).

Data

Our primary data set consists of residential billing data from September 2000 to December 2008. These data provide us with information on kilowatt hours purchased per billing cycle, whether the home generated power, whether the household uses electric heat, and whether the household is enrolled in the utility's renewable energy program, their medical assistance program, or their energy assistance program. We link each billing cycle to the mean daytime and nighttime temperature in that billing cycle.

We merge 2008 credit bureau data to our residential billing data. These credit bureau data provide us with household income; demographic characteristics of the household such as ethnicity, age of the household head, and number of persons in the household; and, the year the house was built and other house characteristics such as square footage, whether the house has a pool, and the type of roof the house has. We also have access to the 2009 credit bureau data. These two cross-sections allow us to create a short panel data set.[5]

The 2008 credit bureau data contain information on 520,835 households and we restrict the sample to the 309,149 single family homeowners. These households are slightly older (a mean age of 55 for the household head) and include fewer household members (a mean of 2.2) compared to a random sample of single family homeowners in the metropolitan area of our utility in the American Community Survey (ACS) of 2005-2008 (where the mean age of the household head is 53 and the mean number of persons in the household is 2.8). We focus on the subset of households who are single family homeowners. Because we only have the credit bureau data at two points in time (2008 and 2009), we know nothing about the demographics of households who lived in a house in our utility's service area before 2008 and then moved even though we observe their electricity consumption.

We merge individual voter registration and marketing data to our data set.[6] For registered voters we know party affiliation, level of education, and whether the individual donates to environmental organizations. We were able to link half of our sample to the voter registration data. (We do not limit our sample to the registered.) We linked either the person whose name was on the utility bill or the first person on the utility bill.[7] The individuals we could not link were living in smaller households and in block groups with a low proportion of the college-educated, were more likely to receive a subsidy for electricity because of their low income, and were more likely to have a household head above age 60.[8] We also merge to

[5] We do have monthly/household panel data for the dependent variable (electricity purchases) but we only have data on the household's demographics from the 2008 and the 2009 credit bureau cross-sectional data sets.
[6] We purchased the data from www.aristotle.com.
[7] Only 5% of households were "mixed" between conservatives and liberals.
[8] Relative to all homeowners in the same county these individuals were also more likely to be of Asian or other ancestry rather than of European ancestry, but were less likely to be Spanish speaking. They were also lower income.

these data, by the block group, the share of registered voters who were liberal (Democrat, Green, or Peace and Freedom) in 2000 and the share of vehicles which were hybrids in June 2009.[9] We expect that environmentalists are more likely to live in liberal, educated communities.

We have access to two other revealed preference measures of a household's environmentalism. From the data base with voter registration information, we know whether a household has donated money to an environmental group and we know whether the household has signed up for the utility's renewable power program. Each household decides whether to opt in and pay a fixed cost of $3 a month to have 50% of its power generated by renewables or $6 a month to have 100% of its power generated by renewables.[10]

We use these data to examine the effects of income, demographics, ideology, and building vintage effects on 2008 daily household energy purchases. We continue our examination of the effects of building vintage on energy purchases using a sample of California owner-occupied, single family homes from the 2000 5% IPUMS (Integrated Public Use Sample). Respondents were asked their annual electricity expenditures. We restrict to households in which the head is ages 30-65. We merge these data to the price of electricity in the home's utility district when the house was built.[11] Because our price data are available from 1960 onward only, we restrict our sample to homes that are at most 40 years old. We use these data to examine whether homes built in years when electricity prices were low used more electricity in calendar year 2000.

[9] The political voter registration data are obtained from http://swdb.berkeley.edu/. While we acknowledge that it is a little bit odd to merge future (June 2009) hybrid registrations to 2008 data, it is important to note that vehicles are a durable good and many of the vehicles were owned as of 2008. We also believe that a block group's hybrid vehicle ownership is extremely highly correlated between 2008 and 2009.

[10] The collected revenue is used by the electric utility to purchase and produce power from wind, water, and sun.

[11] We thank Tom Gorin at California Energy Commission for providing us with data on mean annual residential electricity rates by utility since 1960.

We also examine panel data on electricity purchases to probe the robustness of our results. These data allow us to examine movers and renovators. Our electricity panel data begin in September 2000. For 2005 to 2008 we also have permit data from the Development Services Department of the major city in our utility district. These data indicate the type of renovation (e.g. kitchen, HVAC, electrical, etc), when it was done, and the value of the renovation. We link these data to the single family homeowners in the credit bureau data and to their 2000-2008 billing data. We can thus examine how, in the sub-sample of renovators, energy consumption changes after a renovation.

The full electric utility panel of approximately 50 million billing cycle observations, which includes owners, renters, and apartment dwellers, allows us to examine how different households respond to climate and price changes. We use the panel data set to test whether liberal/environmentalists voluntarily restrain their consumption in the summer (Kotchen and Moore 2007). We also use this panel to investigate the effects on consumption of price changes employing both the variation provided by the modest rate increases and by differences in winter and summer prices. We know the billing cycle that each household is on. For example, some households may be on a July 15th to August 14th cycle while other households may be on a July 4th to August 3rd cycle. Thus two different households in the same calendar year and same month who are on different billing cycles will face *different* climate conditions and electricity prices. To exploit this within calendar year/month variation we take daily average temperature data and use the billing cycle start and end date to calculate the household specific average temperature in that billing cycle. Any two households on the same billing cycle will face the same average temperature but since different households are on different billing cycles within the same month, we have within month variation in climate. The same strategy is used to generate within year/month variation in average electricity prices. The utility's peak season is from May to October. Thus, between April and May prices rise and between October and November prices fall. We exploit these discontinuities to generate within price variation.

Empirical Methods

We run specifications on both cross-sectional and panel data to examine the impact on current electricity purchases of a household's income, ideology, and demographic characteristics; building codes; and electricity rates, including past rates.

Electricity Purchases in the Cross-Section

Our first specification uses the 2008 billing data linked to the credit bureau data. We regress the logarithm of mean daily kilowatt hours purchased by a household in each billing cycle on household and house characteristics and neighborhood ideology, that is we run

1) $$\ln(kWh) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \varepsilon$$

where X_1 is household income; X_2 is a vector of demographic, ideological, and other characteristics including age, ethnicity, whether Spanish is spoken at home, the year the household moved into the house, the number of persons in the household, the party of registration, whether the household donates to environmental organizations, whether the household purchases energy from renewable resources, and the special utility rate of the household (medical assistance or energy assistance); X_3 is a vector of house characteristics (square footage, electric heat, roof type, and whether the house has a pool); X_4 is a vector of census block group characteristics, consisting of the fraction of registered voters who were "liberal" (Democrats, Green Party, or Peace and Freedom) in 2000 and the fraction of registered vehicles that were hybrids in June 2009; X_5 is the mean of daytime and nighttime temperature in the billing cycle (we also examine the interaction between liberal and mean temperature); X_6 is a vector of building year dummies (single years with pre-1960 as the omitted category); and, ε is an error term. The dummies enable us to determine if stronger building codes coincide with improved electricity efficiency. Standard errors are clustered on the household and the block level.

As we discussed in the empirical framework section, we are aware that we are collapsing both discrete choices (over home type and appliances) and continuous choice (utilization) into one outcome measure; monthly electricity consumption. The cost of this approach is that we cannot claim to recover how our explanatory variables affect each of these three choices. Instead, we recover a "total effect".[12]

We estimate Equation 1 using OLS.   Under the standard assumption that E(ε|X) equals zero, this regression recovers a series of treatment effect estimates. For example, if a random person were assigned a swimming pool, we would estimate how her electricity consumption would change. We acknowledge the possibility that people who live in big homes with swimming pools may be "different on unobservables".   If those with an unobserved taste for electricity intensive goods self select to live in large homes that have energy consuming attributes (such as swimming pools), then our OLS estimates will over-state the true causal effects of home size and swimming pools on a random household's electricity consumption. We will discuss panel results where our regression results are identified from within home

[12] Leading structural papers such as Dubin and McFadden (1984) , Goldberg (1998), and Mansur, Mendelsohn, and Morrison (2008) have jointly modeled the decision of durable purchase and utilization.   In the case of cars, a household simultaneously chooses what car to buy and how much to drive it. The price per mile of driving depends on the car chosen, so in a regression of utilization (miles driven) on demographics and price per mile, this last variable is endogenous. It is important to note that we are not following this empirical strategy. Our dependent variable is not "utilization" it is total electricity consumption. We are assuming that the error term in equation (1) is uncorrelated with the unobserved determinants of housing type.

variation (two different families living in the same house) and from families moving within the utility service area (observing the same family living in two different homes).[13]

The marginal and average price that households face for electricity is a choice variable because of the utility's rising block tier pricing system. Households consuming more electricity face a higher marginal price. Recent research (see Borenstein 2009 and Reiss and White 2005) examines whether households are responsive to average or marginal prices. In this paper, we pursue two different strategies (one cross-sectional and one panel) for examining how robust are our results once we control for electricity prices.

In our cross-sectional approach to controlling for electricity prices, we modify Equation 1 to resemble a demand equation. Because prices are potentially endogenous and we do not have a credible instrument, we use Reiss and White's (2005) price elasticity estimate of -0.39. We assume that this price elasticity is the same for all households in our sample, thus ruling differential price responses by demographic group. We then rewrite Equation 1 as

$$ln(kWh) = \beta_0 - 0.39 \times ln(P) + \beta X + \varepsilon$$

where P is the price of electricity and X is a vector of other control variables. Using information on the tier price structure by month, electricity consumption by tier, and the type of rate the household faces (electric homes face different rates), we can calculate each household's average price per kilowatt-hour of electricity by month (P^*). We use this information to redefine our dependent variable as $ln(kWh) + 0.39ln(P^*)$ and rerun Equation 1. This transformation permits us to study the robustness of our results once we control for price.

We further investigate the relationship between year built and household electricity consumption by examining whether households living in houses built in years when energy

[13] These results are based on a short (2008 to 2009) panel for the subset of within electric utility service area movers.

prices were low purchase less energy. We compare houses built in different years in the same neighborhood at the same point in time. Using the 2000 IPUMS we specify the log of annual household electricity expenditure, E, as a function of the logarithm of the mean price of electricity in the electric utility district in the building vintage year (P), a vector of house year built dummies (Y), a vector of house characteristics (H), including electric heat and number of rooms, a vector of socioeconomic and demographic statistics (X), geographical fixed effects (F) called "PUMAs" in the Census data, and an error term (ε):

2) $$ln(E) = \beta_0 + \beta_1 ln(P) + \beta_2 Y + \beta_3 H + \beta_4 X + \beta_5 F + \varepsilon.$$

Our year built dummies are less than 2 years old (the omitted category), 2-5 years ago, 6-10 years ago, 11-20 years ago, 21-30 years ago, and 31-40 years ago. Our socioeconomic and demographic variables include the logarithm of household income, the Duncan Socioeconomic Index, race, the number of persons in the household, and the age of the household. We cluster the standard errors on electric utility district/year built dummies.

Electricity Purchase in the Panel

We continue to investigate how the building stock affects household energy purchases by performing an analysis of variance among a random sample of movers within the electric utility service area. That is, for every single month, we perform a two-way ANOVA, in which we estimate the partial sum of squares for the residence and for the household among non-apartment dwellers. A comparison of the partial sum of squares for the residence and for the household will reveal whether the structure or the family explains a greater proportion of the variance in electricity consumption.

We further analyze how the building stock affects household energy purchases by examining the effect of home renovations on household energy purchases in the major city of the electric utility service area from September to 2000 to December 2008. We regress the logarithm of a household's mean daily kilowatt hours purchased in a billing cycle (kWh) on the mean temperature in the billing cycle (T) and the interaction between mean temperature and the percent of liberals in the block group and between mean temperature and political party of registration (L), a vector of dummy variables (R) indicating whether the household added square footage, a new roof, new windows, a new kitchen, a new HVAC, and a new water heater by the billing cycle date, a vector of dummy variables (W) indicating that work was in progress on a specific renovation, R, and household fixed effects (F):

3) $$ln(kWh) = \beta_0 + \beta_1 T + \beta_2 (TxL) + \beta_3 R + \beta_4 W + \beta_5 F + \varepsilon$$

We also examine interactions between mean temperature and the dummy variables indicating specific renovations. Equation (3) enables us simultaneously to examine the role of renovations in determining electricity consumption and, through testing for whether β_2 is negative, to test the voluntary restraint hypothesis that liberal/environmentalists consume less electricity on hotter days. As a comparison, we present results (without the renovation variables) for the entire electric utility panel of all customers (renters and owners) from 2000 to 2008. Standard errors are clustered on the billing cycle.

We use our panel data to estimate aging effects between 2000 and 2008, enabling us to understand the extent to which our year built dummies are determined by aging. That is, we estimate

4) $$ln(kWh) = \beta_0 + \beta_1 T + \beta_2 A + \beta_3 F + \varepsilon$$

where T is mean temperature, A is current year minus year built, and F is a household fixed effect.

We test the robustness of our cross-sectional estimates by examining movers between 2008 and 2009 linked to the 2008 and 2009 credit bureau data. This second “short” panel allows us to examine households who moved into different homes within the electric utility service area and residences whose owners changed. In looking at households who moved into different homes, we include a household fixed effect and test how the home's attributes (size and year built) affect electricity consumption. In looking at homes with different owners, we include a home fixed effect to study how within home changes in the demographics of the family (income and age) correlate with electricity consumption. Specifically, we estimate

5) $$\ln(kwh) = \delta_{home} + \beta_0 + \beta_1(Household\ Characteristics) + \varepsilon$$

and

6) $$\ln(kwh) = \delta_{house\ hold} + \beta_0 + \beta_2(Home\ Characteristics) + \varepsilon$$

where δ is the home or household fixed effect.

We use the full 50 million panel observations to examine the effect of electricity prices on consumption. We calculate for each year/month in our sample the mean price per kilowatt hour that households faced. This mean price is exogenously determined for any household. Prices vary because of rate changes in 2001, 2005, and 2008 and, more importantly, because of rate increases in the summer. We estimate

7) $$\ln(kwh) = \beta_0 + \beta_1 T + \beta_2 T^2 + \beta_3 \ln(P) + \beta_4 H + \varepsilon$$

where T is temperature in the billing cycle, P is the price, and H is a vector of household fixed effects. Standard errors are clustered on the billing cycle.

Results

Home, Demographic Characteristics and Ideology and Prices

Table 4 reports estimates of equation 1. We estimate a small income elasticity of 0.05 and an elasticity for the square footage of the home of 0.42, holding all factors constant.

Asians, other non-European ethnics, and Spanish language speakers purchase fewer kilowatt hours, perhaps because of unobserved wealth effects. For every ten years of duration living in the home, we estimate that household electricity consumption increases by 1%. We view this variable as proxying for the average age of the durable stock. Note that despite being able to control for a large number of household, structure, and neighborhood attributes, we can explain relatively little of the variance in electricity consumption -- the R^2 in these regressions averages around 0.26.

Our results highlight the role that ideology plays in explaining cross-sectional variation in electricity consumption. Controlling for structure and census block group characteristics and household income and demographics, registered Democrats, Greens, and Peace and Freedom purchase less electricity than registered Republicans, American Party, or Libertarians. A Green consumes 9.6% less than a Republican and a Democrat 3.9% less. Those enrolled in the utility's renewable energy program purchase 1.1% fewer kWh. The greater the fraction of liberals in a block group and the greater the fraction of hybrids among registered vehicles in the block group the lower are electricity purchases.[14] A one percentage point increase in the block's liberal share is associated with 3.6% lower electricity consumption. The second column of Table 4 shows that when we restrict ourselves to warm summer days, we find that voluntary restraint is greater in the summer. Greens consume 11.1% less than Republicans and the coefficient on liberal community jumps from -0.36 to -0.60. We cannot pin down why electricity consumption is lower in more liberal communities. Either liberals who choose to live in liberal communities are more liberal and practice greater voluntary restraint or social pressure in liberal communities encourages individuals to conserve on electricity consumption.

[14] Our demographic results such as household income, age, and household size are in line with previous estimates discussed in studies such as Lutzenhiser (1993), Schipper, Bartlett, Hawk and Vine (1989), Wilson and Dowlatabadi (2007).

When we control for price effects by modifying our dependent variable to equal $ln(kWh) + 0.39ln(P^*)$ and re-run our regressions, our results show a slightly greater reduction in daily kilowatt hours among liberals, customers living in neighborhoods with a high fraction of hybrid vehicles, users of renewable energy and customers living in houses built after 1983 (see Table 4). Accounting for price effects leads to an even greater increase in daily kilowatt hours among customers with a pool and customers living in bigger homes (compare the right column to the left column of Table 4). Electric home customers enjoy a lower average and marginal price (because their steps in the tier system are longer and they face lower winter rates). The positive effect of having an electric home falls slightly once we account for price in our dependent variable.

Building Codes and Year Dummies

California introduced its energy efficiency standards for new construction in 1978. Figure 1, which plots year dummies from the first specification given in Table 4 for every year after 1960 (pre-1960 is the omitted category), demonstrates that electricity purchases for households living in houses built when those codes were implemented are not lower than homes built before these new codes were enacted. Controlling for our host of demographic, structure and ideology variables, we find a distinctive non-monotonic relationship between a home's year built and electricity consumption. Relative to homes built before 1960, homes built between 1960 and 1983 consume roughly 5% more electricity. Homes built in the 1990s consume 15% less electricity than homes built in the 1978 to 1983 period. Starting from 1984 to the present, we observe a monotonic negative relationship between year built and electricity consumption. Relative to homes built before 1960, those living in houses built in 2006 or later consume 16 percent fewer kilowatt hours. When we restrict to hot billing cycles (results not shown), households' increase in daily kilowatt hours is greater for houses built between 1960-

1983 relative to houses built before 1960 and the decline in daily kilowatt hours for post 1992 structures is smaller compared to our results for all billing cycles.

The age of major appliances and controls for insulation cannot account for the building year dummy pattern. When we used a 2008 Home Energy Survey for 495 single family homeowner households, we found that houses built after 1992 were more energy efficient than houses built before 1960 regardless of whether we controlled for the age and type of appliances. Controlling for variables such as the age of the furnace, the age of the HVAC, the type of windows, the presence of insulation, the number of refrigerators, the age of the refrigerator, and the number of LCD and plasma TVs, we found that that coefficient on built in 1992 or later relative to built before 1960 was -0.191 ($\hat{\sigma} = 0.073$). Without these controls, the coefficient was -0.199 ($\hat{\sigma} =0.080$).

Using census data from the calendar year 2000, we observe that in California as a whole households living in houses built in the 1970s have higher annual electricity bills controlling for electric heat, the number of rooms, household income and demographic characteristics, and PUMA fixed effects (results not shown). Compared to houses built after 1998, the coefficients on year built pre-1960, 1960-69, 1970-79, 1980-89, 1990-94, and 1995-98 are 0.092 ($\hat{\sigma}$=.011), 0.132 ($\hat{\sigma}$=.012), 0.151 ($\hat{\sigma}$=.011), 0.124 ($\hat{\sigma}$=.011), 0.080 ($\hat{\sigma}$=.012), and 0.029 ($\hat{\sigma}$=.012), respectively.

Table 5, which looks at houses built after 1959, shows that houses built in periods of low electricity prices are less energy efficient.[15] Between 1960 and 1983 our electric utility's real price of kilowatt hours in 1977 dollars fell from 3.2 cents per kilowatt hour to 2.6 cents per kilowatt hour, reaching a low in the late 1970s. Real prices then rose, reaching a high in the

[15] We restrict ourselves to houses built after 1959 because we do not have electricity price data prior to 1960.

late 1980s and then fluctuating in a narrow band. In other California utility districts the 1970s were a period of low energy rates as well.

Controlling for price in the local utility district and vintage year category, the magnitude of the coefficient on the year built 1970-79 dummy falls from 0.154 to 0.090. The price elasticity of annual electricity expenditures with respect to price at the time the house was built is -0.22, suggesting that low energy prices lead either to less demand for energy efficient homes on the part of owners or to shoddier construction. Low electricity prices also encouraged the building of electric homes. When we estimated a probit model of whether the home was an electric home on the logarithm of the electricity price in the year and utility district when and where the house was built (and controlling for PUMA fixed effects), we obtained a coefficient of -0.058 ($\hat{\sigma}$=.019) on price (this is a derivative of the coefficient on price). However, because we control for electric homes in all of our cross-sectional specifications the pattern that we observe in the year built dummies cannot be explained by whether a home is an electric home.

Movers and Renovators

Our panel data show that while a house is energy inefficient both because of its structure and the people living within it, the house itself accounts for a larger share of the variance in total electricity purchases (see Table 6). Our analysis of variance shows that in a random sample of movers moving to different homes within the utility district between 2000 and 2008, the partial sum of squares for the residence is more than three times larger than the partial sum of squares for the family in July, the hottest month of the year, and the partial sum of squares for the residence is more than two times larger than the partial sum of squares for the family in December, the coldest month of the year.

Cross-sectional regressions (such as equation 1) are subject to the criticism that there may be unobserved features of the home or the household that are correlated with the observables. We use our short panel from 2008 to 2009 and focus on households who moved between electric utility service area homes over this period and on the same house in the electric utility service area with two different owners. Unfortunately, there are only 3,000 such movers. We use these data and estimate Equations 5 and 6. The panel specification that includes a home fixed effect allows us to estimate the role of household size and household income and the panel specification that includes a household fixed effect allows us to estimate the role of housing attributes such as square feet and year built on electricity consumption. All of these results are available on request. The panel results with fixed effects yield "within" estimates that are generally similar to the OLS results estimated on the same sample. This robustness test raises our confidence in our cross-sectional estimates.

We use our full 2000-2008 panel to examine whether aging effects can explain our year built dummies (Equation 4) and conclude that while there are aging effects, these effects are small (results not shown). We find that as a house ages, each additional year increases mean daily kWh by 0.1 percent. (When the dependent variable is the logarithm of mean daily kWh and control variables are temperature, a dummy for summer months, and house fixed effects, the coefficient on house age is 0.0011, $\widehat{\sigma}=0.0005$.)

How much is a house's energy efficiency determined by its year of birth, or can a home renovation change the energy efficiency of the dwelling? Table 8 shows that most renovations increase energy consumption. A new HVAC decreases electricity purchases for mean temperatures below 58.3°F or 14.6°C (roughly the 35th bottom mean temperature decile). At a temperature of 75°F (23.9°C) a new HVAC increases electricity purchases by 5 percent. This finding is consistent with past work documenting a rebound effect associated with new residential durables purchases (see Dubin, Miedema and Chandran 1986, and Davis 2008). Additions of square footage and new kitchens increase daily kilowatt hours purchased by 1.4 and 1.7 percent, respectively. A new roof decreases electricity purchases by 1.6 percent.

Table 8 also presents results for the full panel showing that registered liberals and households living in block groups with a high proportion of liberals reduce their consumption during the summer months. When we use the full panel to investigate the effects of price changes on electricity purchases (Equation 7), we obtain a statistically insignificant coefficient of -0.126 ($\hat{\sigma}$=.081) on the logarithm of the price of electricity (full results not shown). This is smaller than Reiss and White's (2005) price elasticity estimate of -0.28 from OLS estimation and of -0.39 based on GMM estimation. Our estimate is also smaller than Borenstein's (2009) median average price elasticity of -0.217 but well within his estimated range.

Understanding Aggregate Time Series Trends

Between 1980 and 2005 average residential consumption among California electric utilities ranged between 400 and 800 kWh per month (depending on climate zone), with minor fluctuations in residential consumption over this 25 year period (Gorin and Pisor 2007). What accounts for the "flat" California trend? Rising incomes, bigger home sizes, an increase in the share of electric homes from 10% in 1980 to 15% in 1980, and the move to warmer inland areas should increase electricity consumption. But the declining share of energy inefficient homes built in the 1970s (see Table 9) should decrease electricity consumption.

We examine how average household electricity consumption changes as the attributes of California households and structures, the temperature where most people live, and Californians' party registration have changed over time. We begin by estimating a modified version of our 2008 cross-sectional regression (Equation 1) for all electric utility homeowners using in the regression only attributes that are available in the 1980-2000 Censuses and the

2006 American Community Survey, in aggregate voter registration data, and in our cross-sectional data.[16] That is, we estimate

8) $$\text{kWh} = \beta_H(Household) + \beta_S(Structure) + \beta_T(Temperature) + \beta_D(Democrat) + \beta_Y(Year\ Built\ Dummies) + u$$

where the dependent variable is mean daily kWh per billing cycle in July 2008, our household variables are the age of the household head, the number of persons living in the household, and income; the home characteristics are square feet and whether the home has electric heat; Temperature is the mean of daytime and night-time temperature within the billing cycle; Democrat indicates that the utility customer is a registered Democrat; and the eight year dummies are indicators for built prior to 1940, built in 1940-1949, 1950-1959, 1960-1969, 1970-1979, 1980-1989, 1990-1999, and built 2000 or later. We restrict our sample to registered Democrats and Republicans. The regression results are given in Appendix Table 1.

We then calculate average electricity consumption per decade for the average California household who lives in single family housing. We calculate this by using our estimated coefficients, $\hat{\beta}_H, \hat{\beta}_S, \hat{\beta}_T, \hat{\beta}_D, \hat{\beta}_Y$, and sample means for household demographics and politics and structure attributes from the 1980, 1990, and 2000 Census, 2006 American Community Survey and voter registration data. We use county level July average temperature data and calculate a state level mean by calculating the population weighted July temperature exposure in each year. We use aggregate state political voter registration data to calculate the share Democrat in each year. To calculate our electricity consumption index, we combine these data sources along with our index weight estimates from the linear regression (see equation 8) and we estimate for each year t (1980,1990, 2000, and 2006):

[16] Because we do not know square footage from census data we proxy for state-wide square footage using information on square footage by year built under the assumption of random scrappage.

9) $$kWh_t = \hat{\beta}_H\left(\overline{Household_t}\right) + \hat{\beta}_S(\overline{Structure_t}) + \hat{\beta}_T(\overline{Temperature_t}) + \hat{\beta}_D(\overline{Democrat_t}) + \hat{\beta}_Y(\overline{Year\ Dummies_t})$$

Our resulting index resembles a Paasche Index because we use our regression estimates of Equation 8 from 2008 as index weights to collapse the characteristics at each point in time into a single energy index.

Table 10 reports our decomposition results. The units are kWh per day in July. We present the total average consumption by decade and disaggregate this total into the contributions from housing structure, household demographics, climate migration, and politics. Predicted average electricity consumption is rising over time but slowly. The subindices show that different subcomponents are moving in opposite directions. Rising household income and larger homes over time have increased electricity consumption but partially offsetting this is the shrinking share of the housing stock built in the “brown vintages” from 1960 to 1980. Changes in household characteristics (income, household size, and age of the household head) predict greater consumption over time. The move to higher temperature areas has relatively little effect as do changes in the share of registered Democrats. The share of Democrats, however, may be a poor predictor of environmentalism if Democrats have become greener over time.

Although we do not explicitly account for price changes, they are unlikely to explain the flat California trend because prices in California as a whole were relatively flat since the 1980s. Between 1980 and 1990 real prices rose by 12 percent but by 2000 had fallen once more to their 1980 level. By 2006 real prices had risen again to their 1990 level (Gorin and Pisor 2007).

Conclusion

Using several unique datasets we examined cross-sectional and longitudinal variation in homeowner electricity purchases and provided insights into why California's per capita residential electricity consumption has been roughly constant since the 1980s. Our cross-sectional estimates permitted us to account for the role of housing structure, household demographics, and ideology in residential electricity consumption. We then used our cross-sectional estimates in an aggregation exercise where we averaged over housing and household types using the census counts. This aggregation allowed us to study how the average home evolves over time as demolition and new construction takes place and as the housing, socioeconomic, and demographic characteristics of diverse California households evolve.

We conclude that we have not yet seen the full impact of building and appliance code regulation and of today's relatively high electricity prices on California's electricity consumption. We found that California houses built between1960-1983 were less electricity efficient than homes built prior to 1960 (in part because they were built when electricity prices were low), but that after 1983 homes became more electricity efficient (because of higher electricity prices and building code regulations). The past is still with us because homes are long lived durables. The homes born in times of low electricity prices and weaker regulations still constitute a large fraction of the housing stock.

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Table 1: Major Energy Efficiency Changes in Electric Utility Service Area Homes by Vintage Years

Year Built		Expected Increase in Energy Consumption Relative to pre-1950
1950s and earlier	43% of homes have AC system that is less than 6 years old in 2008 47% of electric homes have a furnace that is less than 6 years old in 2008 24% of homes have single pane windows in 2008	
1960s	More efficient air-conditioning (higher SEER) introduced 22% of homes have AC system that is less than 6 years old in 2008 31% of electric homes have a furnace that is less than 6 years old in 2008 23% of homes have single pane windows in 2008	- + +
1970-77	26% of homes have AC system that is less than 6 years old in 2008 10% of electric homes have a furnace that is less than 6 years old in 2008 Forced air furnace with ducts become more common among electric homes 40% of homes have single pane windows in 2008	+ + + +
1978-83	California energy efficiency standards are introduced in 1978 Better roof and wall insulation (lower U-Factor) Central AC with ducts becomes common in 1980s 19% of homes have single pane windows in 2008	- - + -
1984-91	More efficient heat pump (higher HSPF) More efficient air-conditioning (higher SEER) 8% of homes have single pane windows in 2008	- - -
1992-98	Better wall, raised floor, and duct insulation (lower U-Factor) More efficient air-conditioning (higher SEER)	- -
1999-2000	More efficient air source heat pump (higher HSPF) More efficient water heating (higher energy factor)	- -
2001-03	Less duct leakage (higher duct leakage factor) More efficient permanently installed lighting	- -
2004-05	More efficient water heating (higher energy factor)	-
2006 and later	More efficient heat pump (higher HSPF) More efficient air-conditioning (higher SEER) More efficient permanently installed lighting	- - -

Source: 2005 Residential Table – Vintage Values, p. B-12 in California Energy Commission's 2005 Residential Compliance Manual; Residential Compliance Manuals from 1978 to the present; Consol's "Meeting AB-32 Cost-Effective Greenhouse Gas Reductions in the Residential Energy Sector," August, 2008; 2005; 2008 electric utility Home Energy Survey, restricted to single family homes.

Table 2: Electric Utility Prices and Quantity Tiers in 2008

	Tier I	Tier II	Tier III
Winter Season, 2008	8.61	14.76	16
Peak Season, 2008	9.29	15.73	14.76
Quantity Threshold Winter, Standard Rate	1120	1400	1400+
Quantity Threshold Winter, Electric Space Heat Rate	1420	1700	1700+
Quantity Threshold Summer, Standard Rate	700	1000	1000+
Quantity Threshold Summer, Well Rate	1000	1300	1300+
Share of Household/Month Observations in 2008	0.86	0.076	0.065

Note: Prices are in cents per kilowatt hour. Tiers are quantities per month. The Well rate includes the medical rate and the energy assistance program.

Table 3: Distribution of Mean Daily Kilowatt Hours Purchased, 2001-2008

	2001	2002	2003	2004	2005	2006	2007	2008
Percentile								
1%	0.61	0.69	0.66	0.50	0.53	0.47	0.38	0.28
5%	4.79	4.77	4.75	4.41	4.15	4.06	3.96	3.84
10%	7.07	7.15	7.28	7.03	6.74	6.80	6.61	6.62
25%	11.97	12.16	12.53	12.37	12.07	12.39	12.03	12.20
50%	19.32	19.68	20.42	20.30	20.12	20.68	20.07	20.36
75%	29.55	30.16	31.52	31.24	31.43	32.33	31.27	31.61
90%	42.50	43.26	45.33	44.84	45.86	47.00	45.28	45.58
95%	52.63	53.30	55.71	55.19	56.88	58.09	55.97	56.17
99%	79.15	79.00	81.47	81.37	84.28	85.19	82.90	82.72
Mean	22.99	23.35	24.28	24.04	24.17	24.76	23.95	24.16
Std. Dev.	23.93	23.93	25.00	24.56	25.21	25.87	24.44	24.56
Obs.	5,669,586	5,798,231	5,946,534	6,100,644	6,237,420	6,334,983	6,384,535	6,417,628

Note: Each observation is mean daily kilowatt hours purchased by each household in each month.

Table 4: Mean Daily Kilowatt Hours Purchased by Households in Each Month in 2008 Explained by House Structure, Household Income and Demographics, and Ideology

		Mean Temp. > 74	ln(kwh)+ 0.39*ln(Price)
Log(square footage of house)	0.423***	0.421***	0.466***
	(0.007)	(0.007)	(0.008)
Dummy=1 if college educated	-0.005	-0.013***	-0.004
	(0.003)	(0.004)	(0.004)
Log(household income)	0.054***	0.060***	0.057***
	(0.003)	(0.004)	(0.004)
(age of household head)/1000	0.982*	-0.919	0.672
	(0.557)	(0.626)	(0.592)
(age squared of household head)/1000	-0.041***	-0.032***	-0.040***
	(0.005)	(0.006)	(0.005)
Year moved into house	-0.001***	-0.001***	-0.001***
	(0.000)	(0.000)	(0.000)
Dummy=1 if			
African-American	0.013	0.014	0.014
	(0.010)	(0.011)	(0.010)
Asian	-0.157***	-0.175***	-0.173***
	(0.007)	(0.007)	(0.007)
Other non-European	-0.109***	-0.116***	-0.116***
	(0.008)	(0.009)	(0.008)
Speaks Spanish at home	-0.023***	-0.028***	-0.025***
	(0.006)	(0.008)	(0.007)
Number of persons in household	0.085***	0.084***	0.092***
	(0.001)	(0.001)	(0.001)
Mean of daytime and nighttime temperature	0.007***	0.044***	0.008***
in billing cycle	(0.000)	(0.002)	(0.000)
Fraction hybrids among registered vehicles in	-3.990***	-5.223***	-4.388***
block group in June 2009	(0.440)	(0.457)	(0.483)
Fraction liberal (registered Democrats, Green	-0.362***	-0.603***	-0.383***
Party or Peace and Freedom) in block group	(0.031)	(0.036)	(0.033)
Dummy=1 if registered			
Republican, Libertarian, or American Party			
Green or Peace and Freedom	-0.096***	-0.111***	-0.106***
	(0.014)	(0.016)	(0.015)
Democrat	-0.039***	-0.041***	-0.043***
	(0.003)	(0.003)	(0.003)
Unidentifiable party	-0.061***	-0.066***	-0.067***
	(0.005)	(0.005)	(0.005)
No Party	-0.032***	-0.029***	-0.036***
	(0.006)	(0.006)	(0.006)
Dummy=1 if not registered	-0.081***	-0.102***	-0.083***
	(0.003)	(0.004)	(0.003)
Dummy=1 if donates to	-0.005	-0.012**	-0.006
environmental groups	(0.005)	(0.005)	(0.005)
Dummy=1 if enrolled in			
renewable energy program	-0.011***	-0.002	-0.016***

	(0.004)	(0.005)	(0.004)
medical rate program	0.239***	0.269***	0.261***
	(0.006)	(0.007)	(0.007)
energy assistance program	0.051***	0.058***	0.049***
	(0.005)	(0.005)	(0.005)
Dummy=1 if house has			
electric heat	0.320***	0.113***	0.303***
	(0.008)	(0.008)	(0.009)
Pool	0.338***	0.322***	0.376***
	(0.004)	(0.005)	(0.005)
Solar	-0.597***	-0.641***	-0.624***
	(0.053)	(0.057)	(0.055)
Dummy=1 if roof is			
wood shake	-0.061***	-0.066***	-0.065***
	(0.006)	(0.007)	(0.006)
cement/concrete	-0.007	0.000	-0.005
	(0.005)	(0.006)	(0.005)
Composition	-0.062	-0.089	-0.055
	(0.133)	(0.161)	(0.137)
Other	-0.597***	-0.641***	-0.624***
	(0.053)	(0.057)	(0.055)
Building year dummies	Y	Y	Y
Observations	2,596,645	660,514	2,587,342
R-squared	0.269	0.259	0.281

Note: The sample consists of single family homeowners linked to the credit bureau data and to their 2008 electricity data. Each observation is a household's billing cycle. See Equation 1 in the text. The dependent variable is the first three specifications is the logarithm of mean daily kilowatt hours purchased by the household in the billing cycle. The dependent variable in the fourth specification is ln(kwh)+0.39ln(Price). Daily kilowatt hours purchased is bottom-coded at 2.09 kilowatt hours. Mean daily kilowatt hours is 28.9. Standard errors (in parenthesis) are clustered on the billing cycle and block level. *** p<0.01, ** p<0.05, * p<0.1 Additional covariates are dummy variables indicating unknown year the house was built, unknown square footage, unknown age of household head, unknown family income, and unknown number of household members. The constant term is not shown. Building year dummies are plotted in Figure 1.

Table 5: Electricity Prices at Time of Home Construction, Vintage Effects, Income, and Annual Electricity Expenditures

	Coefficient	Std. Err.	Coefficient	Std. Err.	Coefficient	Std. Err.
Log(Average Real Price of Electricity in Utility/Home Vintage Category			-0.194***	0.024	-0.224***	0.038
Dummy=1 if built before 1998						
1995-1998	0.030	0.021			0.052***	0.019
1990-1994	0.080***	0.020			0.116***	0.018
1980-1989	0.126***	0.019			0.127***	0.017
1970-1979	0.154***	0.019			0.090***	0.020
1960-1969	0.137***	0.019			0.117***	0.017
Electric heat	0.219***	0.011	0.222***	0.012	0.219***	0.011
Log(household income)	0.116***	0.004	0.115***	0.004	0.116***	0.004
Duncan Socioeconomic Index	0.066***	0.010	0.065***	0.010	0.066***	0.010
White	0.083***	0.007	0.087***	0.007	0.083***	0.007
Number of rooms	0.090***	0.003	0.088***	0.003	0.090***	0.003
Number of persons	0.056***	0.004	0.057***	0.004	0.056***	0.004
Age of household head	0.005***	0.000	0.005***	0.000	0.005***	0.000
Constant	4.276***	0.067	4.686***	0.079	4.630***	0.100
Observations	139,343		139,343		139,343	
R-squared	0.165		0.163		0.165	
PUMA fixed effects	YES		YES		YES	

Note: Estimated from the 2000 5% IPUMS for all California owner-occupied, single family homes in which the household head is ages 30-65 and the home is 40 years old or less. See Equation 2 in the text. The dependent variable is logarithm of annual electricity expenditures. The mean of annual electricity expenditures is $889. The standard errors are clustered on electrical utility/built year categories.

Table 6: Variance in Mean Daily Kilowatt Hours Among Movers Explained by Family and Residence, By Month

	Partial SS	DF	MS	F
January, 733 obs.				
Model	572.133	582	0.983	7.86
Residence	482.412	519	0.940	7.52
Family	18.754	69	1.549	12.39
February, 740 obs				
Model	530.931	561	0.946	9.08
Residence	454.175	495	0.918	8.80
Family	99.176	66	1.503	14.42
March, 708 obs				
Model	482.046	543	0.888	10.24
Residence	419.063	480	0.873	10.07
Family	79.476	63	1.262	14.55
April, 698 obs.				
Model	514.300	461	0.944	10.97
Residence	430.897	84	0.935	10.87
Family	84.582	152	1.001	11.71
May, 674 obs.				
Model	525.352	513	1.024	16.66
Residence	427.056	432	0.989	16.08
Family	104.464	81	1.290	20.98
June, 611 obs.				
Model	538.048	474	1.135	19.17
Residence	435.445	392	1.111	18.76
Family	80.249	82	0.979	16.53
July, 558 obs.				
Model	633.410	417	1.519	12.39
Residence	496.582	339	1.465	11.95
Family	152.350	78	1.953	15.93
August, 512 obs.				
Model	604.199	396	1.526	6.15
Residence	478.546	323	1.482	5.97
Family	162.720	73	2.229	8.98
September, 520 obs.				
Model	470.250	386	1.22	19.99
Residence	368.362	302	1.22	20.01
Family	133.91	84	1.594	26.15
October, 446 obs.				
Model	369.079	337	1.095	13.25
Residence	245.802	259	0.949	11.48
Family	123.866	78	1.588	19.21
November, 413 obs.				
Model	246.731	300	0.822	7.38
Residence	180.545	239	0.755	6.78
Family	71.295	61	1.169	10.48
December, 485 obs.				
Model	272.943	365	0.748	6.91
Residence	182.613	286	0.639	5.90
Family	75.894	79	0.961	8.87

Note: We restricted the 2000-2008 billing data to families that moved within the electric utility service area in those years. We then generated random samples in every month and restricted to residences that are not apartments.

Table 7: Mean Daily Kilowatt Hours in July Purchased by Movers Explained by Family and Residence Characteristics

	(1)	(2)	(3)
Percent liberal (registered Democrats, Green	-0.354**		-0.575***
Party or Peace and Freedom) in block group	(0.137)		(0.171)
Number of persons in household	0.082***	0.048	
	(0.006)	(0.178)	
Logarithm of household income	0.095***	0.095	
	(0.020)	(0.425)	
Logarithm of square footage	0.313***		0.216***
	(0.045)		(0.037)
Dummy=1 if house built			
Before 1960			
1960-1991	0.111***		0.058
	(0.038)		(0.040)
1992+	-0.055		-0.046
	(0.042)		(0.044)
Residence fixed effects		Y	
Family fixed effects			Y
Observations	5,923	5,923	6,052
R-squared	0.095	0.982	0.805

Note: The sample consists of all houses in 2008 and 2009 that changed ownership and where we could trace the same family. Robust standard errors, clustered on the census block group, are in parentheses. *** p<0.01, ** p<0.05, * p<0.1 Additional covariates are a dummy indicating the year is 2008 and dummy variables indicating unknown year the house was built, unknown square footage, and unknown family income.

Table 8: Home Renovations, Average Temperature, Ideology, and Energy Purchases, 2000-2008

	All Households		Renovators in the Major City			
	OLS Coef.	Std. Err.	OLS Coef.	Std. Err.	OLS Coef.	Std. Err.
Mean temperature	0.015***	0.002	0.009***	0.002	0.009***	0.002
(Mean temperature) x (fraction liberals in block group)	-0.016***	0.001	-0.007**	0.003	-0.007**	0.003
(Mean temperature) x Dummy =1 if Republican, Libertarian, or American Party (omitted)						
Green or Peace and Freedom	-0.001***	0.000	-0.003***	0.000	-0.003***	0.000
Democrat	-0.000***	0.000	-0.001***	0.000	-0.001***	0.000
No Party or Unidentifiable	0.000	0.000	-0.002***	0.000	-0.002***	0.000
Not registered	-0.000	0.000	0.002***	0.000	0.002***	0.000
(Mean temperature) x						
Dummy=1 if renewable energy	-0.000	0.000	-0.001***	0.000	-0.001***	0.000
Dummy=1 if donates to environmental groups	-0.001***	0.000	-0.000	0.000	-0.000	0.000
Dummy=1 if added						
Square footage					0.014***	0.004
New roof					-0.016***	0.004
New windows					0.000	0.006
New kitchen					0.017***	0.005
New HVAC					-0.175***	0.029
New water heater					-0.004	0.004
(Average temperature) x (New HVAC)					0.003***	0.000
Observations	49,147,306		1,156,982		1,156,982	
R-squared	0.7549		0.715		0.715	
Household fixed effects	Y		Y		Y	

Note: Each observation is a household's billing cycle. The renovators sample estimates Equation 3. The dependent variable is the logarithm of mean daily kilowatt hours purchased by a household in the billing cycle. The all households sample consists of all electric utility customers, regardless of dwelling type or ownership status, from September 2000 to the end of 2008. Mean daily kilowatt hours in this sample is 18.6. The renovators sample consists of single family homeowners in the major city in the electric utility service area who are in the credit bureau data, are linked to their September 2000-2008 electricity data, and completed a renovation with a permit between 2004-2008. Mean daily kilowatt hours in the renovators sample is 24.2. Standard errors are clustered on the billing cycle. *** p<0.01, ** p<0.05, * p<0.1 Additional covariates are a time trend and a time trend squared and dummies for repair periods. The constant term is not shown.

Table 9: California's Durable Housing Stock by Birth Cohort and Calendar Year

Birth Period	1980	1990	2000	2006
2000+				.09
1990-1999			.14	.12
1980-1989		.20	.16	.14
1970-1979	.23	.19	.17	.15
1960-1969	.22	.18	.16	.14
1950-1959	.26	.21	.19	.17
1940-1949	.14	.11	.09	.08
Pre-1940	.15	.11	.10	.10

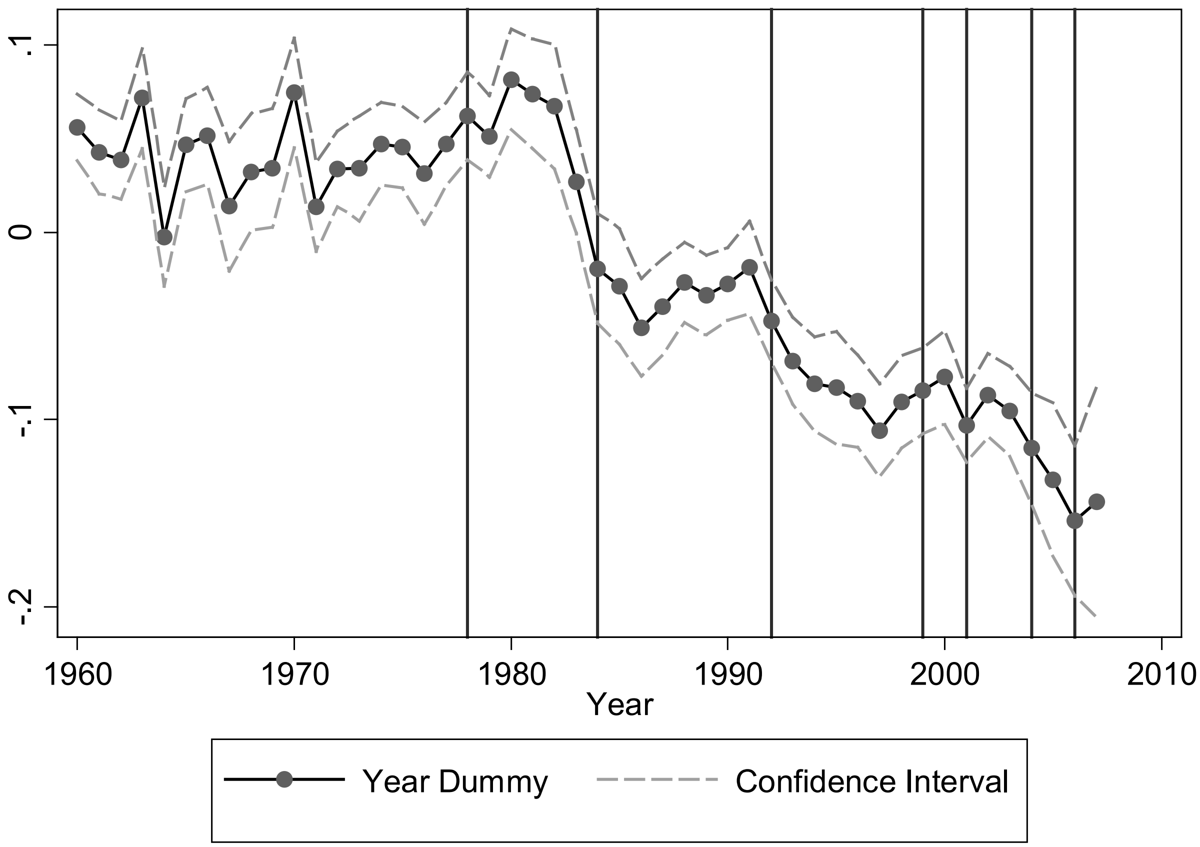
Note: Estimated from the 1980-2000 IPUMS and 2006 ACS. The housing stock only includes single family homes.

Table 10: Decomposition Results, Mean July Daily kWh

	1980	1990	2000	2006
Total	36.917	38.287	39.387	39.921
Home (year built, electric home)	-2.328	-1.814	-2.006	-3.381
Home (square feet)	16.899	17.895	18.536	19.257
Household (age, income, household size)	10.154	9.837	10.491	11.626
Climate (Mean July Temp)	13.905	13.947	13.964	13.985
Ideology (Democrat/(Democrat+Republican))	-1.713	-1.578	-1.599	-1.565

Note: We estimated index weights, β_{2008}, from the 2008 cross-sectional regression given in Appendix Table 1. The units are kWh. This table reports estimates of Equation 9 in the text.

Figure 1: Effect of Year Built on Mean Daily Kilowatt Hours Purchased by Households in Calendar Year 2008



Note: Building year dummies are from the first regression in Table 4. All dummies are relative to built prior to 1960. The vertical lines indicate the years building code legislation became effective: 1978, 1984, 1992, 1999, 2001, 2004, and 2006.

Appendix Table 1: Mean Daily Kilowatt Hours Purchased by Households in July 2008 Explained by House Structure, Household Income and Demographics, and Ideology

Dependent variable = mean daily kWh	
Square footage of house	0.012***
	(0.000)
Household income	0.000***
	(0.000)
Age of household head	-61.014***
	(3.355)
Number of persons in household	3.116***
	(0.065)
Mean of daytime and nighttime temperature in billing cycle	0.192***
	(0.017)
Dummy=1 if registered as	
Democrat	-2.827***
	(0.141)
Dummy=1 if house has electric heat	4.944***
	(0.445)
Dummy=1 if house built	
before 1940	-7.929***
	(1.398)
1940-1949	-5.276***
	(1.347)
1950-1959	-1.844
	(1.326)
1960-1969	-1.501
	(1.337)
1970-1979	-0.175
	(1.347)
1980-1989	-3.531***
	(1.364)
1990-1999	-5.791***
	(1.350)
2000+	-12.658***
	(1.301)
Observations	97,583

Note: The sample consists of single family homeowners linked to the credit bureau data and to their 2008 electricity purchase in the month of July. See Equation 8 in the text. The sample is restricted to registered voters who are either registered Republican or Democrat with non-missing information on year built, square footage, age of household head, family income, and number of household members. Each observation is a household's billing cycle. The dependent variable is mean daily kilowatt hours purchased by the household in the billing cycle. Daily kilowatt hours purchased is bottom-coded at 2.09 kilowatt hours. Mean daily kilowatt hours is 30.7. Standard errors (in parenthesis) are clustered on the block level. *** p<0.01, ** p<0.05, * p<0.1. There is no constant term in the specification.