NBER WORKING PAPER SERIES

ELECTRICITY CONSUMPTION AND DURABLE HOUSING: UNDERSTANDING COHORT EFFECTS

Dora L. Costa
Matthew E. Kahn

Working Paper 16732
http://www.nber.org/papers/w16732

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
January 2011

We thank Tom Gorin and Erin Mansur for sharing data with us. We thank Catherine Wolfram and conference participants at the December 2009 UC Berkeley Green Buildings Conference for useful comments. We thank the Richard Ziman Real Estate Center at UCLA for generous research funding. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

Electricity Consumption and Durable Housing: Understanding Cohort Effects
Dora L. Costa and Matthew E. Kahn
NBER Working Paper No. 16732
January 2011
JEL No. Q41,Q58

ABSTRACT

We find that households living in California homes built in the 1960s and 1970s had high electricity consumption in 2000 relative to houses of more recent vintages because the price of electricity at the time of home construction was low. Homes built in the early 1990s had lower electricity consumption than homes of earlier vintages because the price of electricity was higher. The elasticity of the price of electricity at the time of construction was -0.22. As homes built between 1960 and 1989 become a smaller share of the housing stock, average household electricity purchases will fall.

Dora L. Costa
Bunche Hall 9272
Department of Economics
UCLA
Box 951477
Los Angeles, CA 90095-1477
and NBER
costa@econ.ucla.edu

Matthew E. Kahn
UCLA Institute of the Environment
Department of Economics
Department of Public Policy
Box 951496
La Kretz Hall, Suite 300
Los Angeles, CA 90095-1496
and NBER
mkahn@ioe.ucla.edu

Residential buildings represented 21% of total electricity consumption in the United States in 2007. Since 1970, residential retail electricity sales per housing unit increased by 58 percent.[1] Relative to the nation, California stands out as an exception as its residential retail electricity sales per housing unit increased by only 33 percent between 1970 and 2007.[2] Explanations for this divergence, called the Rosenfeld curve (named after Arthur Rosenfeld of the California Energy Commission), 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 (Dan Charles 2009).

We use micro data from the 2000 Census to document the electricity consumption of California homes of different vintages and to establish how the price of electricity at the time when a home was built determines its later electricity consumption. At any point in time, the average home's electricity consumption is a weighted average of that of different cohorts of homes in which the weights are the vintage's share of the total housing stock. Because housing is a durable and because we find that the real price of electricity at the time when a home is built is an important determinant of its later electricity consumption even when 40 years have passed, inefficient cohorts have a long-run effect on the average home's electricity consumption at later points in time.

Empirical Framework and Data

---

[1] Total retail electricity sales are from the Energy State Data System (SEDS) of the Energy Information Administration http://www.eia.doe.gov/emeu/states/_seds.html . The number of housing units are estimated from the 2006 American Community Survey and from United States Department of Commerce (1993).

[2] See footnote 1 for sources.

A home's electricity consumption depends on how it was built, who lives in the home, what durables are installed in the home and how the household uses these durables for its day to day activities. Below, we will control for attributes of the household living in the home. Our focus is the home itself and the building codes and energy prices when it was constructed.

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 building codes, technology, and energy prices at the time of construction. Houses built during years of low electricity prices may be less energy efficient because consumers demand less efficient houses. We seek to understand the differences between vintages.

We use a sample of California owner-occupied, single family homes from the 2000 5% IPUMS (Integrated Public Use Sample) to examine the effect of electricity prices in the year the home was built on current energy expenditures. Respondents were asked their annual electricity expenditures. We restrict to households in which the head is ages 30-65. The Census reports expenditure on electricity, the household's attributes, the home's attributes and provides a geographical identifier called a "PUMA". Such PUMAs are aggregates of adjacent census tracts and tend to have roughly 100,000 people within them.

Using the 2000 IPUMS we compare houses built in different years in the same PUMA at the same point in time. 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 (S), geographical fixed effects (F) called "PUMAs" in the Census data, and an error term (ε):

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

The PUMA fixed effects proxy for local climate conditions and current electricity prices. The coefficient on price, β_1, is thus equivalent to the price at construction elasticity of total electricity consumption.

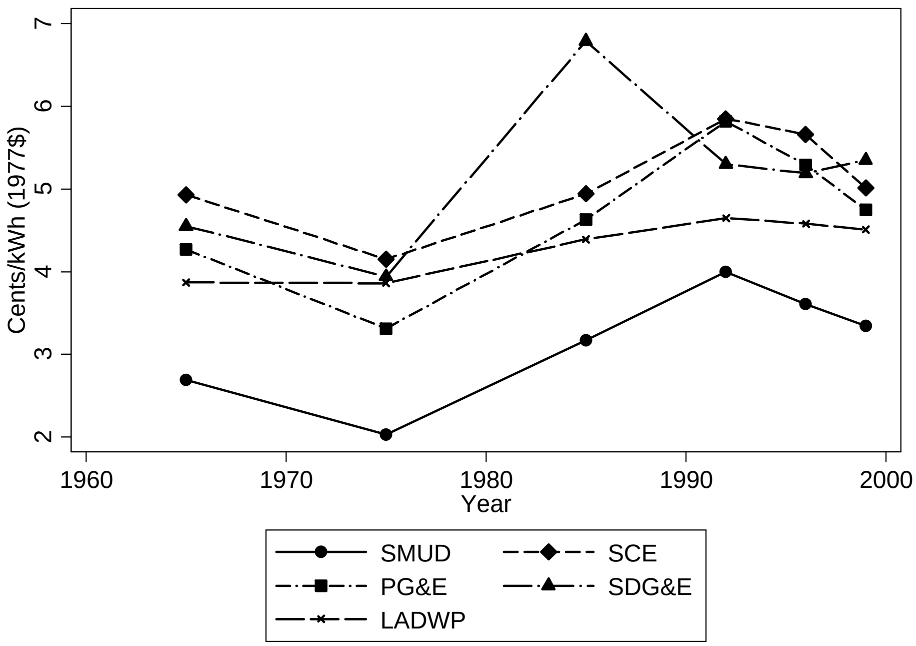
We estimate equation (1) using OLS to test for differences in energy expenditure as a function of the home's year built. We restrict our sample to single family homes built between 1960 and 2000. Because of data availability our year built dummies are less than 2 years old (after 1998, the omitted category), 2-5 years ago (1995-1998), 6-10 years ago (1990-1994), 11-20 years ago (1980-1989), 21-30 years ago (1970-1979), and 31-40 years ago (1960-1969). Our socioeconomic and demographic variables include the logarithm of household income, the Duncan Socioeconomic Index (a measure of the household head's occupation which we view as a proxy for permanent income), race, the number of persons in the household, and the age of the household head. In addition, we control for the home's number of rooms, an electric heat indicator and we include the year built dummies listed above.

Both building codes and electricity prices at the time of construction will affect vintage year dummies. Real electricity prices in California were falling in the 1960s and 1970s and only began to rise in the 1980s, peaking in the early 1990s in 4 out 5 utilities (see Figure 1). California prices were similar to the rest of the nation in 1970 but consistently higher after 1985[3]. We would expect that homes built in the 1970s would be less energy efficient than earlier and

[3] See the Energy State Data System (SEDS) of the Energy Information Administration.

later homes. An increased prevalence of heating and cooling systems with ducts (a source of energy leakage) might reduce the energy efficiency of homes built in the 1970s relative to earlier years.

FIGURE 1 – REAL PRICE (CENTS/KWH) BY CALIFORNIA UTILITIES, 1960-2000



Notes: The data were kindly provided by Tom Gorin and are in 1977 dollars. We present the means for 1960-69, 1970-79, 1980-89, 1990-94,1995-98, and 1999-2000.

The California Energy Commission (CEC) requires that new construction meet a specific energy budget in terms of energy consumption per square foot of floor space and that certain standards, e.g. for insulation, are met. The CEC instituted energy efficiency building codes in 1978 and subsequently strengthened the codes in 1984, 1992, and 1998. However, building codes could be ineffective if there is a “rebound” effect leading consumers to increase electricity usage (e.g. cranking up the air conditioning) or if builders do not effectively implement the code (e.g. they install poor insulation).

Using data from a large California public utility with information on home characteristics, including square footage and the exact year built, and on homeowner characteristics, Dora L. Costa and Matthew E. Kahn (2010) found that homes built after 1983 use less electricity than home built before 1960, coincident with stricter building codes. However, they found that homes built in the 1970s and early 1980s use more electricity than homes built before 1960 despite the introduction of building codes. In the 2000 IPUMS data the 1998, 1992, 1992 or 1984, and 1984 or 1978 codes governed year 1998 and later, 1995-98, 1990-94, and 1980-1989 homes, respectively. For the most part, codes did not affect 1960-1979 construction.

We estimate equation (1) with and without average electricity prices at the time when the home was built. We use the Mable Geocorr mapping file to map PUMAs to counties. For each major utility district in California for each year from 1960 until 2000, we have data on the real price per kWh of residential electricity.[4] Our price data set covers the major California electric utilities: SCE, PG&E, SMUD, LADWP, and SDG&E.

Erin Mansur provided us with a bridge file that allowed us to assign each county to a specific utility. The IPUMS data reports a home's year built in roughly ten year categories. Using this information and the home's PUMA location we merge the average real electricity price to each record. For example, suppose that in the year 2000, there is a home built between 1960 and 1970 in the Sacramento area. Using the Mansur data, we will assign this home as being part of SMUD's service area. We take the SMUD real annual price data and average it

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

from 1960 to 1970 and merge this average SMUD price to this Sacramento home to reflect the price of electricity when it was "born". When a county was served by more than one utility (such as Los Angeles County), we averaged across the two utility's prices. We cluster the standard errors by electric utility/built year interval since the average electricity price does not vary within this category.

Our data are only for California because this is the state for which we have been able to collect historical data by decade by electric utility. A novel feature of these data is that two different homes in the same PUMA will have different "birth" electricity prices if they were built in different time periods and two homes built in the same year will have different "birth electricity" prices if they are located in different electric utility zones. We exploit both sources of variation below.

Results

We find a non-monotonic relationship between electricity consumption and vintage year (see Table 1). When we do not control for the price of electricity at the time of construction, we find that compared to homes built in 1998-2000, homes built in the 1960s, 1970s, 1980s, early 1990s, and mid-1990s consume 14, 15, 13, 8, and 3 percent more electricity, respectively. When we control for the price of electricity at the time of construction, we find that homes built in the 1960s, 1970s, 1980s, early 1990s, and mid-1990s consume 12, 9, 13, 12, and 5 percent more electricity, respectively, than homes built in 1998-2000. Past prices thus explain 42% of the difference between in electricity consumption between 1970-79 and 1998-2000 homes and 15% of the difference between 1960-69 and 1998-2000 homes. Controlling for electricity prices we find that homes built in the 1980s and early 1990s consume as much electricity as homes built in 1998-2000. Lower electricity usage in early 1990s homes thus can be fully explained by price effects. Only in the second half of the 1990s did homes start to consume less electricity controlling for prices at time of construction.

TABLE 1 – ELECTRICITY PRICES AT TIME OF HOME CONSTRUCTION, VINTAGE EFFECTS, AND ANNUAL ELECTRICITY EXPENDITURES (IN LOGS)

	Coefficient	Coefficient
Log(mean real price of electricity in year built in local utility)		-0.224***
		(0.038)
Dummy=1 if built		
after 1998 (omitted)		
1995-1998	0.030	0.052***
	(0.021)	(0.019)
1990-1994	0.080***	0.116***
	(0.020)	(0.018)
1980-1989	0.126***	0.127***
	(0.019)	(0.017)
1970-1979	0.154***	0.090***
	(0.019)	(0.020)
1960-1969	0.137***	0.117***
	(0.019)	(0.017)
Observations	139,343	139,343
R-squared	0.165	0.165
PUMA fixed effects	YES	YES

*Note*s: 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 1 in the text. The dependent variable is logarithm of annual electricity expenditures. The mean of annual electricity expenditures is $889. The standard errors (in parentheses) are clustered on electric utility/built year categories. Additional control variables are a dummy for electric heat, the logarithm of household income, the Duncan Socioeconomic Index, a dummy if the head of the household is white, the number of rooms, and the number of persons in the household, the age of the household head. The constant term is not shown. The symbol *** indicates significance at the 1 percent level.

We estimate an elasticity of electricity prices at the time of construction of -0.22. When we drop the year built dummies in the specification, we estimate a price elasticity of -0.194 ($\hat{\sigma} =$ 0.024). Our estimated elasticity of the price at the time of construction is higher than Koichiro Ito's (2010) estimate of the elasticity of current average price of -0.112.

Low electricity prices at the time of construction encourage the building of electric heat homes; we found that electricity expenditure is 21.9% ($\hat{\sigma} =$ 1.1) higher for owners of electric heat homes relative to comparable non-electric heat homes. Estimates from a probit model showed that a dollar decrease in the price of electricity at the time of construction (controlling for PUMA fixed effects) increased the probability that a home was an electric heat home by 0.058 ($\hat{\sigma}$=.019). However, because we include an electric heat dummy 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 heat home.

Homes built in the 1970s are not high electricity cost homes because of aging effects. We recognize that in a single cross-section that we cannot disentangle birth cohort effects from aging effects. Costa and Kahn (2010)'s panel analysis of a large sample of California homes from a major electric utility district covering the years 2001 to 2009 showed that each 10 years of aging increases a home's electricity consumption by 1%. This very small aging effect increases our confidence that the estimated effects in Table 1 reflect vintage effects.

Given that homes are extremely long lived durables, energy inefficient cohorts will affect overall average household electricity consumption for decades. Table 2 shows that the share of "brown" vintages built in the 1970s has fallen as population has grown and new homes have been constructed. In Table 2, we report the birth year vintage distribution by calendar year for California. To construct this table, we have taken Census micro data from 1980, 1990 and 2000 and data from the 2006 American Community Survey and tabulated the birth year by calendar year. The columns sum to 1. In 1980 homes built in the 1970s represented 23% of the stock while by the year 2006 this cohort's share had shrunk to 15%.

Table 2: California's Housing Stock Shares by Birth Cohort and Calendar Year

Birth Period	1980	1990	2000	2006
2000+				.10
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

Notes: Estimated from the 1980-2000 IPUMS and 2006 ACS. The housing stock is restricted to single family homes.

Conclusion

Low electricity prices at the time of construction are an important determinant of a home's electricity consumption even years after its birth. This finding resembles results from the induced innovation literature (see Richard Newell, Adam B. Jaffe, and Robert N. Stavins 1999) for air conditioners and vehicles. During times of high energy prices, producers market more energy efficient versions of the differentiated product. As homes built between 1960 and 1989 become a smaller share of the housing stock and new homes are built under existing or even more stringent codes, then, all else equal, average household electricity purchases will fall.

References

Charles, Dan. 2009. "Leaping the Efficiency Gap." *Science*, 325 (August 14): 804-811.

Costa, Dora, and Matthew E. Kahn, 2010. "Why Has California's Residential Electricity Consumption Been So Flat since the 1980s?: A Microeconometric Approach." National Bureau of Economic Research Working Paper 15978.

Ito, Koichiro. 2010. “Do Consumers Respond to Marginal or Average Price? Evidence from Nonlinear Electricity Pricing.”
http://ecnr.berkeley.edu/vfs/PPs/Ito-Koi/web/JMP_Koichiro_Ito_UC_Berkeley_2010_1122.pdf

Newell, Richard, Adam B. Jaffe, and Robert N. Stavins. 1999. The Induced Innovation Hypothesis and Energy Saving Technological Change. *Quarterly Journal of Economics*, 114(3): 941-975.

United States Department of Commerce. **Economics and Statistics Administration. Bureau of the Census.** 1993. “1990 Census of Population and Housing. Population and Housing Unit Counts, United States. 1990 CPH-2-1.” Washington DC: U.S. Government Printing Office.