California Public Utilities Commission

Electricity Use and Income:
A Review

POLICY AND PLANNING DIVISION
LITERATURE REVIEW

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CALIFORNIA PUBLIC UTILITIES COMMISSION

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Table of Contents

Summary

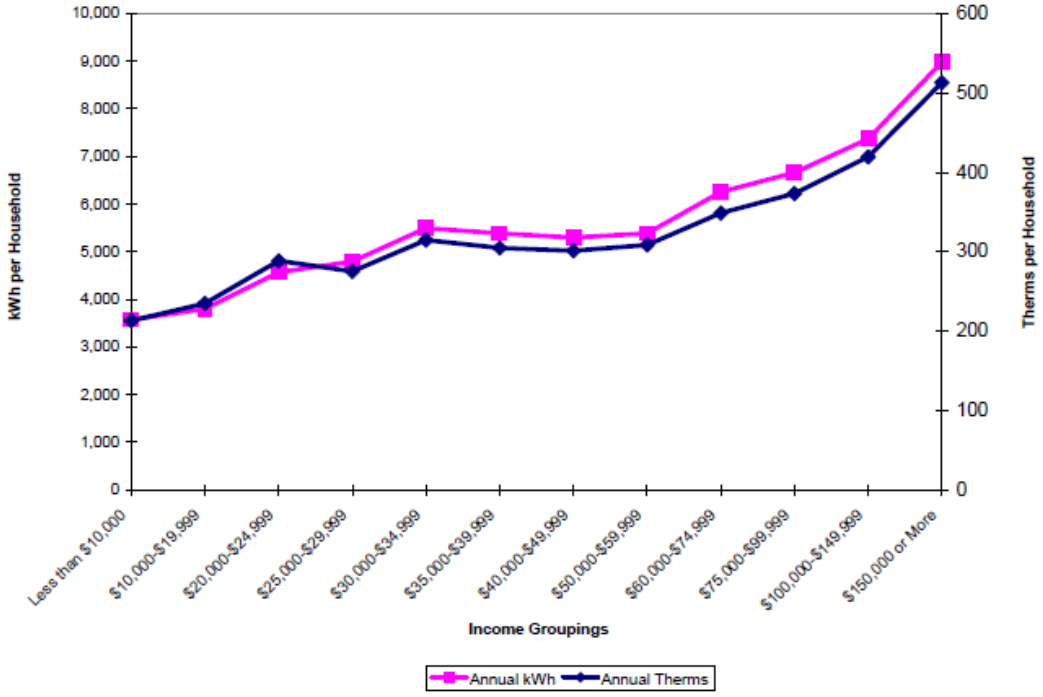
The study of relationship between residential electricity demand and income is important as it helps to better understand welfare implications of various policies. According to the 2009 California Residential Appliance Saturation Study, there is a positive correlation between electricity use and income, but the strength of the relationship is not stated in the report. However, that does not mean all low-income consumers are low energy-users. Two common measures used to analyze the impact of changes in income and prices on energy use, price elasticity and income elasticity of demand, are derived from estimation of a demand function. The literature on modeling residential electricity consumption is extensive. Unfortunately, few studies provide findings on the distribution of elasticities across household income levels.

Introduction

Modeling residential demand for electricity has been an important topic since 1970s due to the interest in conservation and impact of increasing electricity prices on welfare. The models estimated throughout the years differ in various characteristics: functional form, estimation method, data type, and others. As the average price paid for residential electricity has increased over the years, the impact of rising costs on different income groups has remained a concern. Therefore, the relationship between electricity use and income remains to be a major interest for scholars, policy analysts, and policy makers. Scholars explore various modeling techniques and use available data in creative manners to overcome data limitations.

According to the 2009 California Residential Appliance Saturation Study, households, on average, used 6,296 kilowatt-hours (kWh) of electricity in the state, a 6% percent increase from 2003 (KEMA, 2010). According to this study, electricity as well as natural gas use increase with income level in the state, as shown in Figure I.

Figure I. Average Electricity and Natural Gas Consumption by Income



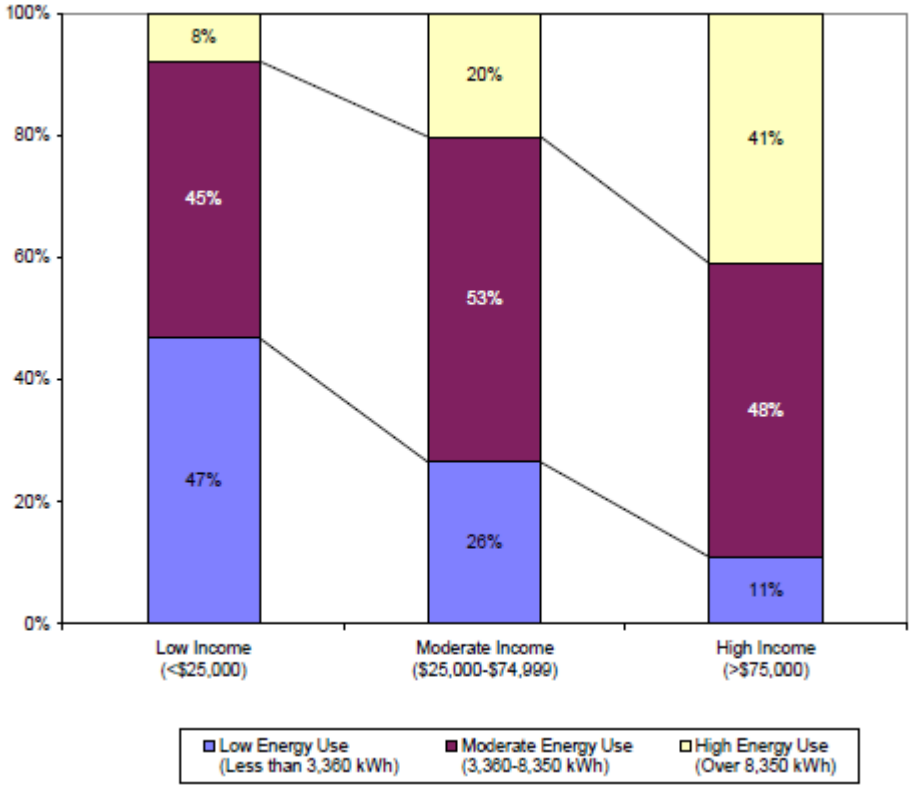
Source: KEMA (2010), p. 32.

The same study also concludes that despite the positive correlation between electricity use and income, all levels of electricity use are observed in every income level.[1] 8% of the low-income households are categorized as high-energy users (over 8,350 kWh per year), whereas 11% of high-income households are low-energy users (less than 3,360 kWh per year). Moreover, it summarizes characteristics of California households. Accordingly, high-income households live in new houses, own more houses, and live in smaller households.[2]

[1] We would like to note that the report does not provide a correlation coefficient for the dataset which has more than 24,000 observations. The chart provided shows the relationship between average electricity use per household and income groupings. That is, the report refers to the correlation between averaged variables. Measures of central tendency, such as an average, reduce the variation observed for the variable. Therefore, it is possible that, the correlation between income groupings and average electricity use appear to be more significant than correlation between actual income and electricity use. In fact, Borenstein and Davis (2011) show that for natural gas, the correlation between average natural gas use and income is positive, but weak.

[2] See Marcus (2002) and Marcus (2007) for similar descriptive analyses for all California utilities. Marcus (2002) concludes that electricity use increases as income increases: Without controlling for family size and housing characteristics, electricity use by households with incomes over $100,000 is 200-250% of the use of households under $15,000 for all utilities and climate zones.

Figure II. Electricity Consumption by Income Grouping



Source: KEMA (2010), p. 33.

Table I. Household Characteristics by Income

	Low income (<$25,000)	**Moderate Income ($25,000-$74,999)**	**High income (>%75,000)**
% of Population	24	40	36
Dwelling Size	1,149	1,420	1,942
Dwelling Age	37.8	36.7	33.9
% Single Family	41	58	75
% Own	42	65	84
Number of People	6.38	4.30	3.78
Annual Electric Consumption per Household	4313	5887	8013
Annual Natural Gas Consumption per Household	249	316	437

Source: KEMA (2010), p.33.

Data as shown in Table I is important in order to understand the relationship between electricity use and income. However, there does not appear to be much consensus on the best approach to model residential electricity demand and accurate estimations of price and income elasticity.

In the next section, we will review the major studies conducted to compute empirical estimates of price and income elasticity of electricity demand using national, regional, and international data and highlight some of their findings.

Literature Review

A typical household electricity demand function shows the relationship between electricity use and variables such as price of electricity, household income, household characteristics, including household demographic information, as well as weather data.

The demand function provides two important estimates describing the relationship between electricity use, income, and prices:

- *Income elasticity* shows the percent change in quantity demanded given a percent change in income.[3]
- *Price elasticity* shows the percent change in quantity demanded given a percent change in prices.[4]

These measures can be computed for short-run and long-run periods. While short-run estimates take the households' appliance stock as constant, long-run estimates allow for adjustments in appliance stocks, thereby incorporate potential technological changes.

Empirical estimates of income and price elasticity show wide ranges. This variation may depend on the following factors (Espey and Espey, 2004, Alberini, 2011):

- Demand function specification
- Data characteristics
- Time interval and geographic location
- Price specification and rate structure[5]

[3] Income elasticity is positive for a normal good and negative for an inferior good.
[4] If price elasticity is less than -1, the demand is said to be elastic; price increase results in more than proportionate quantity decrease. If it is equal to -1, the demand is said to be unit elastic; changes in price and quantity are proportionate. For an inelastic curve, price elasticity is greater than -1.

- Econometric estimation method.

The literature on the estimation of income and price elasticity is extensive. A meta-analysis by Espey and Espey (2004) reviewed 36 articles on residential electricity demand published between 1971 and 2000. In these studies:

- Short-run (SR) price elasticity estimates range from -2.01 to -0.004 (with a mean of -0.35), whereas long-run (LR) price elasticities range from -2.25 to -0.04 (with a mean of -0.85).
- Short-run income elasticities estimates range from 0.04 to 3.48 (with a mean of 0.28) and long-run income elasticities range from 0.02 to 5.74 (with a mean of 0.97).
- Demand specification, data characteristics, time and location, and the estimation techniques contribute to the observed variation, as expected.

Alberini et al (2011) also reviews 16 studies, published between 1999 and 2010, using different levels of data (nationwide, household level, etc.) collected at different geographic areas in order to show the variation in price elasticity estimates. In these studies short run price elasticities range from -0.08 to -1.1.

Even though the variations reported may seem small, Reiss and Weiss (2005) observe the following:

> "Price elasticity differences of seemingly small amounts (e.g. -0.28 vs. -0.39) are economically quite important in electricity markets. Assuming residential demand is too inelastic by this difference of -0.1 when increasing the marginal rate by (say) three cents per kWh would overestimate annual revenue for California's larger utilities by approximately 75 million dollars."[6]

National studies:

- Alberini (2011) examines the residential demand for electricity, using nationwide household level data for 1997-2007. The dataset, which is a mixed panel, cross-section data, covers 50 largest metropolitan areas in the United States. While the authors find strong response to price changes in the range of -0.86 to -0.67, they also find that the price elasticity of demand declines with income, but the magnitude is rather small. For

[5] Even though most studies use average prices in modeling residential electricity demand, whether consumers respond to average or marginal prices and which one should be used in modeling electricity demand is still a topic of debate. Shin (1985) argues that consumers respond to average prices rather than marginal prices. Ito (2010) also finds no evidence that consumers respond to marginal prices.
[6] Reiss and White (2005), p. 869, footnote 24.

example, the price elasticity is -0.68 for households in the first quartile, -0.67 in the second quartile, -0.66 among the third, -0.64 in the fourth. It is argued that the income elasticity is low due to correlation with other factors such as housing characteristics. However, even when such characteristics are removed, it increases to only 0.05.

- Assuming consumers respond to average electricity prices, Fell et al. (2010) estimate the residential electricity demand for different regions in the U.S. They find that price elasticity estimates vary across the regions, the South being the most price-elastic region (-1.02) and the Northeast being the least elastic region (-0.82). These estimates are larger than other residential demand estimates that use household level data. The authors explain that the difference is most likely due to the assumption that consumers respond to average prices rather than marginal prices. They also find that price elasticities do not vary much across income quartiles. Finally, the authors find that income elasticities are small across the regions in the range of 0.05 to 0.11.
- Bernstein and Grifin (2007) show that there are regional and state differences in the price-demand relationship for electricity and natural gas. They find that there is some consistency in residential electricity use among states within a region and differences among regions in demand and price trends. Their findings also indicate that the demand is relatively inelastic to price and this relationship has not changed much since 1980s. They conclude that there may be few options available to the consumer in response to changes in the price of energy, and that price does not respond much to changes in demand. They also argue that since prices in real terms have been declining over the study period, "the inelasticity of demand may be more of an artifact of the lack of price increases."

Studies on California and other states or metropolitan areas:

- Reiss and White (2005) use 1993 and 1997 RECS data and evaluate alternative tariff designs by taking into account variation in demand elasticities, and other household characteristics. They estimate the mean annual short-run elasticity as -0.39. The authors report that compared to the previous studies that find elasticities in the range of zero to -0.6, and studies conducted by electric utilities that find elasticities in the range of -0.15 to -0.35, their results appear to be within the range. They disaggregate their finding to show heterogeneity in price sensitivity across households with varying incomes, appliance holdings, etc.

Table III. Price and income elasticities for California households

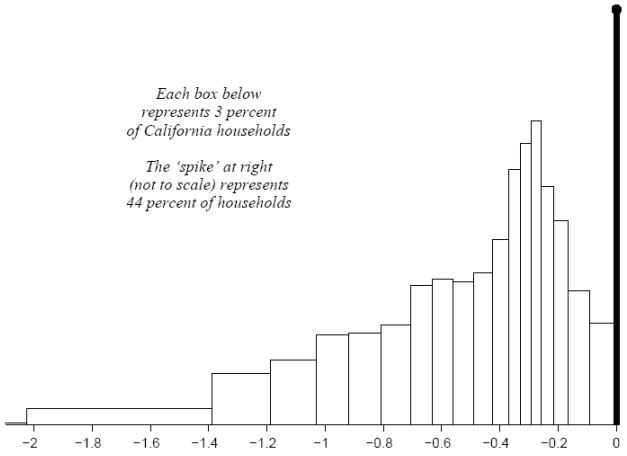
	Price elasticity	Income elasticity
All households	-0.39	-0.00
Households with	-1.02	-0.00
No electric space heating	-0.20	-0.00
Central or room air conditioning	-0.64	0.02
No air conditioning	-0.20	-0.01
No electric space heating Nor air conditioning	-0.08	-0.01

Source: Reiss and White (2005), p. 868.

The authors report that households with electric space heating or air conditioning have higher price elasticities compared to those without air conditioning. Households without such systems have a price elasticity of almost zero. Accordingly, one can conclude that households with electric systems have price elasticity to a certain extent and those who do not are price-insensitive, on average.

Reiss and White construct the distribution of the price elasticity and conclude that 44% of households in California are price insensitive. Approximately 1 in 8 households would respond to price changes, only. The authors' findings confirm the view that households with lower incomes are more sensitive to changes in prices than households with medium or high incomes. However, the magnitude of this variation is rather small, as shown in Table IV below.

Figure III. Distribution of price elasticities



Source: Reiss and White (2001) Figure 2. p. 870

Table IV. Price elasticities by income and electricity consumption

Quartile	**Quartile Range**	**Price elasticity**
By household annual income		
1st	<$18,000	-0.49
2nd	$18,000 to $37,000	-0.34
3rd	$37,000 to $60,000	-0.37
4th	>$60,000	-0.29
By household annual electricity consumption		
1st	< 4450 kWh	-0.46
2nd	4450 to 6850 kWh	-0.35
3rd	6580 to 9700 kWh	-0.32
4th	> 9700 kWh	-0.33

Source: Reiss and White (2005), Table 4, p. 871.

- Another recent draft study California Climate Change Center (2009) cite block rate pricing and joint consumption as two factors that complicate household energy demand consumption estimation. Their price elasticity estimate is -0.29, which is slightly below

than what has been reported in literature, implying that pricing policies may have less impact than expected.

- Pointing out to studies that show negative correlation between electricity consumption and income for regions of the United States, Fullerton et al (2012) examine how electricity use behaves in Seattle, Washington. They show that residential electricity consumption is a normal good in the short run, but an inferior good in the long run. When the income growth is higher than 1.2%, electricity use goes down. They also find out that residential electricity consumption is inelastic to changes in prices.

International cases

- Using large surveys conducted in the province of Québec from 1989 to 2002, Bernard (2011) studies the dynamic behavior of household electricity consumption by using 25 cohorts. These cohorts have on average 131 households. Short-run (-0.51) and long-run (-1.32) price elasticity is found to be statistically significant. The estimate of the income elasticity is not statistically significant.
- Jamasb and Meier (2012) examine the major factors influencing household energy expenditures and the variability of their effects across income levels in Great Britain. They use panel data over the time period of 1991-2007 and consider five income groups. They find that even though energy spending changes with income level, the direction of change is clear. They provide a nice summary of studies conducted other European countries as well, which will not be repeated here. While the estimated income elasticity is 0.06 for the whole dataset, it is lowest for the lowest income group, then increases up to a certain income level, and then decreases again. Same pattern applies to the estimated price elasticity. Households on low incomes are less sensitive to electricity price changes.

Conclusion

As we have reviewed above, scholars have been questioning the factors affecting household electricity use and modeling the relationship between income and electricity use. As described, there is no consensus on the estimates since many factors such as model specification and data used affect the study estimates. As concluded by California Climate Change Center (2009):

> "Elasticity is certainly less a "natural law" than a dynamic description of the relationship between price and consumption. These relationships vary by time and location and model specification, and perhaps many other factors as well. Methodological differences and the

> type of data matter and limit the degree to which results are comparable. In this and most similar estimates, statistical precision is low and uncertainties are high." p. 18.

Given all the choices that go into modeling residential electricity demand function, it is expected that the estimates vary across studies and this variation poses external validity as a problem. That is, we may not extrapolate the results of one study since data may be stale, limited to certain geographical areas, may contain too few observations, or may not capture sufficient price variation. Therefore, it might be judicious to pick a few representative estimates as approximations to inform policy decisions, but not exact numbers.

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