MODELS FOR UNDERSTANDING RESIDENTIAL ELECTRICITY USE

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ABSTRACT
A huge array of human activities including business is supported by generating and consuming electricity. The residential sector accounts for the largest share of electricity use in the U.S. and the greatest share of revenue to power generators. This paper uses government collected data on household electricity consumption to closely examine some of our demand for electricity. The focus is on a specific pathway or mechanism of residential electricity consumption rather than the general drivers. While income is generally predicted by microeconomics to be a driver of demand, I find that household income drives the presence of entertainment-related appliances in homes and further moderates the level of their use.

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Introduction

A huge array of human activities including business are supported by generating and consuming electricity, which is used to power everything from lighting and communications to commercial and industrial production to some of our heating, cooling and cooking to healthcare (medical equipment, hospitals) to entertainment. Electricity is consumed by any appliance or equipment that plugs into an electrical outlet or uses a rechargeable battery. This paper uses government collected data on household electricity consumption to closely examine some of our demand for electricity. The focus is on bringing to an econometric model of electricity demand, tools more commonly used elsewhere in the social sciences to study and statistically test a specific pathway or mechanism of residential electricity consumption.

In 2005, the United States generated over 23% of globally produced electricity. Accounting for population size, the U.S. per capita electricity consumption is one of the ten highest in the world, outpaced by only a handful of high-income countries which also have much colder or hotter average temperatures (Iceland, Canada, Norway, Sweden, Qatar).[1] Contrasting with this somewhat is electricity intensity – or electricity consumed per dollar of GDP – which was roughly flat in the OECD region from 1980 to 2000 and much lower compared to the Former Soviet Union and Eastern Europe. Electricity intensity rose the fastest in this period in the Middle East and North African region, reaching levels similar to the OECD region.[2]

The residential sector accounts for the largest share of electricity consumption in the U.S., comprising more than a third of the total and slightly more than the commercial sector.[3] The residential sector also pays the highest average price for electricity and accounts for the greatest share of revenue to power generators.[4] From the perspective of U.S. households and their energy use, more income is spent on electricity than all other fuels combined, if one excludes spending on transportation (i.e., gasoline for automobiles). In 2001, households spent an estimated $160 billion on energy including $100 billion on electricity, equating to an average $935 per

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[1] Energy Information Administration (EIA), International Energy Annual, 2005, www.eia.doe.gov/pub/international, viewed July 21, 2008.
[2] EIA, World Energy Use and Carbon Dioxide Emissions, 1980-2001, May 2004, www.eia.doe.gov/emeu/cabs/carbonemiss/index.html, viewed July 21, 2008.
[3] Note, the industrial sector uses a greater mix of energy sources.
[4] EIA, Electric Power Annual 2006, www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html, viewed July 22, 2008.

household or 3-4% of average household income.[5] Almost two-thirds of household electricity consumption is for appliances, including refrigerators and lights.[6]

In the United States, the costs of fossil fuels used to generate over 80% of electricity rose at an average rate of 12% per year between 2002 and 2007.[7] The environmental impacts of people generating electricity include the emissions of pollutants and greenhouse gases. Because of the vital role played by electricity and the economic and environmental impacts of its consumption, understanding the nature of our demand for it is important for enabling us to make the best possible choices about electricity consumption and for informing policy makers.

While income is generally predicted by microeconomics to be a driver of demand, the modeling results presented here use tests of mediation models to confirm a hypothesized mediation pathway that household income drives the presence of entertainment-related appliances (stereos, VCRs, televisions) in homes and further moderates the level of their use. These results emphasize the specific pathway or mechanism of residential electricity consumption, and in doing so, employ an extremely simplified demand representation.

The sections below look first at related literature, followed by the data and methodology used, and the results and their implications.

Literature

There is abundant published research exploring electricity consumption, including with focus on the residential sector. Some literature emphasizes engineering considerations to investigate how electricity consumed is affected by the relevant stock of buildings or equipment.[8] Other research is built on econometrics, applying data such as those on consumption, prices, and income to

[5] EIA, Residential Energy Consumption Survey, www.eia.doe.gov/emeu/RECS, viewed July 21, 2008.

[7] EIA, Electric Power Monthly, www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html, Table 4.1, viewed July 28, 2008.

[8] Apte, J. and D. Arasteh (2008) Window-related energy consumption in the US residential and commercial building stock. Lawrence Berkeley National Laboratory, University of California. LBNL-60146. http://repositories.cdlib.org/lbnl/LBNL-60146

economic models of demand. This literature has been evolving since at least the 1950s and 60s, and it confirms the positive association between income and electricity consumption.[9]

In economic theory, households combine electricity with capital stock such as appliances and the type of home in order to meet a demand for lighting, indoor temperature, etc. that is influenced by preferences. The theoretical demand for electricity is predicted to be a function of income, the price of electricity or the services that result from it (heating), the price of possible substitutes, and the factors that influence preferences such as temperature.[10] The role of capital stock implies both short and long-run responses to electricity prices (elasticities), and most recent literature focuses on the short-run. In the long-run, decisions to acquire or replace appliances and housing reflect an equilibrium with manufacturers or suppliers of these products, which increases the complexity of modeling and data needs.

Franklin M. Fisher and Carl Kaysen published an early seminal study of electricity demand in 1962. For the residential sector, they considered the short-run demand for electricity as a function of income and price, and separately, they investigated the long-run demand for appliances. More recently, a working paper from the National Bureau of Economic Research (NBER) has reconsidered household electricity demand.[11] The authors point out that because electricity supply is a regulated industry, pricing is generally nonlinear and reflects tariff systems that cannot change fluidly. As a result, modeling issues may arise due to considerations such as pricing tariffs or tiers designed for specific customer groups (for example, discounts for lower-income consumers) and consumers self-selecting or assigning themselves along the nonlinear pricing schedule.

In a fairly separate area of the social sciences, a literature has grown on the use of pathway analysis and structural equations to focus on intermediary and mediation variables, including more robust statistical analysis of such pathways.[12] A mediation variable or a mediator is one

[9] See Fisher and Kaysen (1962) and more recently, Reiss and White (2001) as well as Narayan et. al (2007).
[10] Narayan, Paresh K.; Smyth, Russell; and Prasad, Arti; "Electricity consumption in G7 countries: A panel cointegration analysis of residential demand elasticities;" Energy Policy (2007) 35: 4485-4494.
[11] Reiss and White (2001).
[12] Used particularly in the fields of psychology, sociology and epidemiology, see Introduction to Statistical Mediation Analysis, by David P. MacKinnon (2008), Lawrence Erlbaum Associates, New York.

that "transmits the effect of an independent variable on a dependent variable."[13] Understanding mediators can be particularly important, for example, in health-related prevention and treatment research.

For economists, understanding mediation pathways is not typically an area of interest. In the example of this paper, income and appliance stocks (specific ones are studied here) are drivers of electricity consumption. It may seem quite obvious that income is also a driver of the appliance stocks (which in turn influence electricity consumption). However, the tools demonstrated here and used to confirm this mediation pathway also have the potential to indicate *how much* of the income effect is transmitted through the appliance stocks.

Gaining a better understanding of the intermediary way that appliance stock influences electricity consumption has possible value to energy economists and policy makers, particularly in the United States, where rising energy prices are putting renewed focus on energy efficiency. In a context of seeking to understand and possibly alter the human consumption of energy (while also increasing the value derived from energy data that is available), this paper introduces an opportunity to apply tools less commonly familiar in energy economics.

Another area of related research and literature worth noting is that of Bayesian networks, which uses a different approach to probability and the consideration of uncertainty or hypotheses. For the set of relationships under study here, one could apply a Bayesian network approach, but that is left for future work.

Although most econometric models do not account for the intermediary pathways by which a driver of demand, such as income, influences electricity consumed, one recent urban studies paper does look at causal pathways of residential energy consumption. Ewing and Rong consider the impact of urban form (density, centrality, accessibility) on residential energy use.[14] The authors hypothesize that residents of sprawling counties are more likely to live in big houses, leading to higher residential energy use (urban form → housing stock → residential

[13] *Ibid.*, p. 8.
[14] Ewing, Reid and Rong, Fang, "The impact of urban form on U.S. residential energy use," Housing Policy Debate (2008) 19:1.

energy consumption). In part because of data limitations, Ewing and Rong test each leg of this causal path separately with different data sets, and they do not test for the direct relationship (urban form → residential energy consumption). Because the authors cannot test for the influence of the housing stock on energy consumption *while controlling for the direct influence of urban form on energy consumption*, because they cannot compare the role of the direct path with the role of the hypothesized causal path, and because they cannot test the two legs of the causal pathway simultaneously (their product) for statistical significance, one cannot be certain that their hypothesized causal pathway is statistically significant.

This paper uses simple econometric modeling of demand and applies a statistically robust version of mediation modeling tools more commonly used in psychology and epidemiology to consider the pathway by which income influences the demand for residential electricity for appliances and lighting. The approach is applied in a limited fashion here, which is intended to introduce the methods of testing for mediation pathways. A logical next step of this research would be to improve on the model presented here into more fulsome econometric analysis.

Data

Data about household electricity consumption is available from the federal Energy Information Administration (EIA), which conducts a periodic Residential Energy Consumption Survey (RECS).[15] The survey is conducted approximately every four years and includes questionnaire items on housing characteristics, appliances, energy use and expenditures. Results presented here use the most recent public microdata available as of June 2008, which is for 2001.[16]

The sampling design of this survey is not a random sampling across the population of U.S. households, and details of the methodology are available from the EIA website. The survey sampling is based on a multistage area probability design wherein the population universe is divided into successively smaller, statistically selected areas. The population is defined as all housing units occupied as primary residence in 50 states and the District of Columbia, estimated

[15] See http://www.eia.doe.gov/emeu/recs/
[16] Data downloaded in June 2008 from the following website: http://www.eia.doe.gov/emeu/recs/recs2001/publicuse2001.html

at 106,989,000 by the Current Population Survey (CPS).[17] This excludes group quarters such as barracks, dormitories, and nursing homes. The final housing units to be surveyed were randomly selected by computer. In results reported here, I treat the data for households as if they were randomly selected from the overall population. Incorporating each household's population weighting into the analysis does not alter the results significantly (R-squares increase and there are slight changes in estimated coefficients). In the long run, however, the probability design of the survey and possible impacts should be further explored.

The survey plan called for 5000 plus 500 supplemental completed interviews (500 supplemental interviews to be representative of households receiving financial energy assistance). Complete interviews were obtained for 4822 eligible households using a multi-wave, multi-contact approach to minimize non-response.

The research reported here investigates only a subset of household electricity consumption -- I exclude the amount of electricity that is consumed for space heating and water heating in order to simplify. The reason is that other fuels compete significantly with electricity to supply these services (including natural gas for both space and water heating, and heating oil for space heating) causing variance in electricity consumption due to fuel competition. This suggests a more complicated demand function and dynamics that could interfere with testing of the mediation relationship under study. In the mediation model, I also exclude electricity used for air conditioning which (together with space heating) may vary with changes in average temperature across the United States. The electricity consumption remaining should be primarily for lighting and appliances. In future studies, it could be possible to incorporate these excluded parts of residential electricity consumption in an expanded demand model.

The variable for household income (Income) as used in this paper is taken directly from the survey data (where it is named MONEYPY). The variable for appliances used here is compiled by summing survey data for component stereos, VCRs, TVs including big screen TVs, personal computers, and aquariums. There is opportunity for improving upon this variable definition by

[17] In this survey, the terms "housing unit" and "household" are treated interchangeably, with the definition of household available from the U.S. Bureau of the Census.

considering other luxury appliances for which data is available or the relative amounts of electricity used by different types of appliances included in this variable. The indicator for electricity price (Price) is calculated from the survey data by taking the estimated electricity cost in dollars (DOLLAREL) and dividing by the estimated electricity consumption (BTUEL). Data for variables representing number of people in the household and home size are available directly from the survey.

Methodology

The conceptual models used with this survey data begin with a simple electricity demand relationship that higher levels of household income (Income) are associated with higher levels of electricity consumption (Elec), as depicted in Figure 1a (below). Three other demand predictors are included – home size (Sqft), electricity price (Price), and number of people in the household (People). I test for this relationship (and most others described below except where noted) using statistical regression analysis. In this simplest case, the relationship is tested using linear regression, with electricity consumption as the dependent variable as represented by this equation:

$$\text{Elec} = i + c\text{*Income} + d_1\text{*Sqft} + d_2\text{*Price} + d_3\text{*People} + e \qquad (1)$$

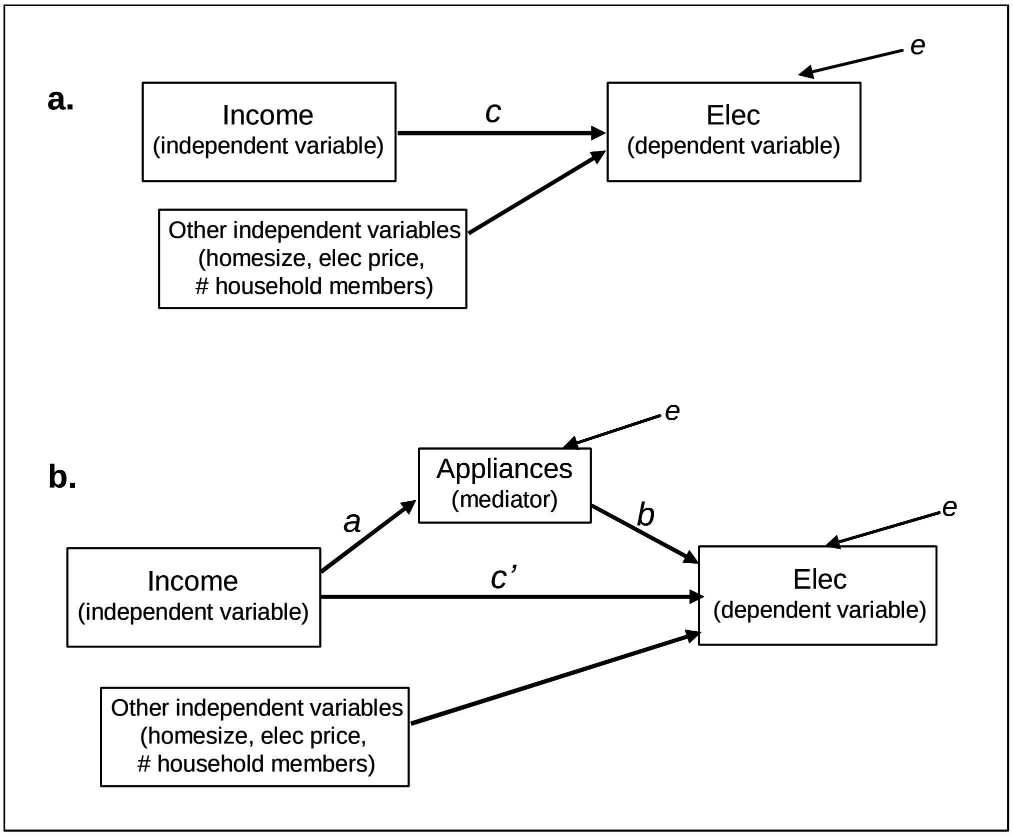
Heteroskedasticity in the data is addressed by using White's method to test whether the regression coefficients are non-zero. The variable for appliances is excluded from this first model so that later comparisons are possible.

Income may have a positive association with electricity consumption, but why? One part of the explanation may be that households with higher income have more electricity consuming appliances, and therefore they consume more electricity. The mediation model that higher household incomes lead to more appliances in the home and that this contributes to higher electricity consumption is depicted in Figure 1b.[18] I consider whether this model holds true for

[18] Note, testing for mediation models is discussed in detail in Introduction to Statistical Mediation Analysis, by David P. MacKinnon (2008), Lawrence Erlbaum Associates, New York.

major entertainment appliances including stereos, VCRs, TVs (also big screen TVs), and aquariums ("Appliances").

Figure 1. Models of household electricity consumption



A mediation model (Figure 1b) can be represented and tested using a pair of equations. First, mediation cannot occur if income does not affect the mediator, household appliances (higher income predicting more appliances), so this is tested with the following equation:

$$\text{Appliances} = i + a{*}\text{Income} + e \quad (2)$$

Second, electricity consumption is positively affected by both income and appliances, as in the following regression equation, which includes the other initial demand variables:

$$\text{Elec} = i + c'{*}\text{Income} + b{*}\text{Appliances} + d_1{*}\text{Sqft} + d_2{*}\text{Price} + d_3{*}\text{People} + e \quad (3)$$

Under the mediation model, the pathway represented by $a*b$ (see Figure 1b) should be statistically significant, and the pathway represented by c' should be smaller compared to the simple relationship between income and electricity consumption (c in Equation 1 above). For many economists, testing the portion of the pathway represented by "*a*" may seem obvious or unnecessary, as well as testing and confirming the significance of the $a*b$ path. Instead, the focus would simply be on Equation 3 with the inclusion of appliances as a demand factor. However, in a world in which energy efficiency matters, understanding how much of the income effect is transmitted thru appliance choices could help to establish policy or public education priorities.

Unlike mediation which helps to explain *why* electricity consumption varies with income, sometimes the relationship between an explanatory variable (such as income) and the dependent variable (electricity consumption) varies according to the presence of another explanatory variable. Some areas of social science call this relationship moderation, although for economists considering a demand equation, it might simply be recognized and represented as an interaction.

To highlight the difference with mediation, I test a simple moderation model related to household electricity consumption. In this case, the definition of electricity consumed no longer excludes that which is used for air-conditioning. In this model, the relationship between income and electricity consumption could vary by average area temperature (CDDs[19]) because there is a discretionary spending aspect to air cooling: a lower-income household may choose to use air-conditioning more judiciously and cool the home on fewer days, or cool it to a relatively higher temperature, or even cool fewer spaces in the home. In contrast, a higher-income household may choose to use air-conditioning over a larger number of days and cool all spaces to a relatively lower temperature. In other words, as the number of CDDs increases, the use of air-conditioning may climb more steeply for higher-income households.

[19] Cooling Degree Days (CDDs) are defined as the number of degrees the average daily temperature (ADT) is above the base temperature of 65 degrees Fahrenheit. Daily degree-days (base 65 degrees) are first calculated as follows:

ADT = (daily high + daily low)/2 *AND*:

CDD(daily)	= 0	if ADT <= 65
	= ADT - 65	if ADT > 65

Annual degrees days are calculated by summing the daily degree days. Note, .5 is carried over in the summation, and the total is rounded up after the summation.

A moderator-type model is depicted in Figure 2a and is generally tested by including an interaction term between two independent variables of a regression model. In this case:

$$\text{Elec} = i + b_1\text{*Income} + b_2\text{*CDD} + b_3\text{*(Income*CDD)} + e \qquad (4)$$

I test this moderator model on a subset of the survey data consisting of single family home households because ambient temperature impacts could be greatly reduced in various forms of attached housing including apartments, condominiums, and townhouses.

Finally, Figure 2b shows an example of a moderated mediation model, which I also test. In this particular case, I test that income not only drives the presence of entertainment related appliances in homes, but also further moderates the level of their use. For example, higher income households may not only have more TVs and entertainment appliances, but at higher levels of income, households may also have more leisure time or opportunity to enjoy such entertainment.

Figure 2. Diagrams of example moderation and moderated-mediation models

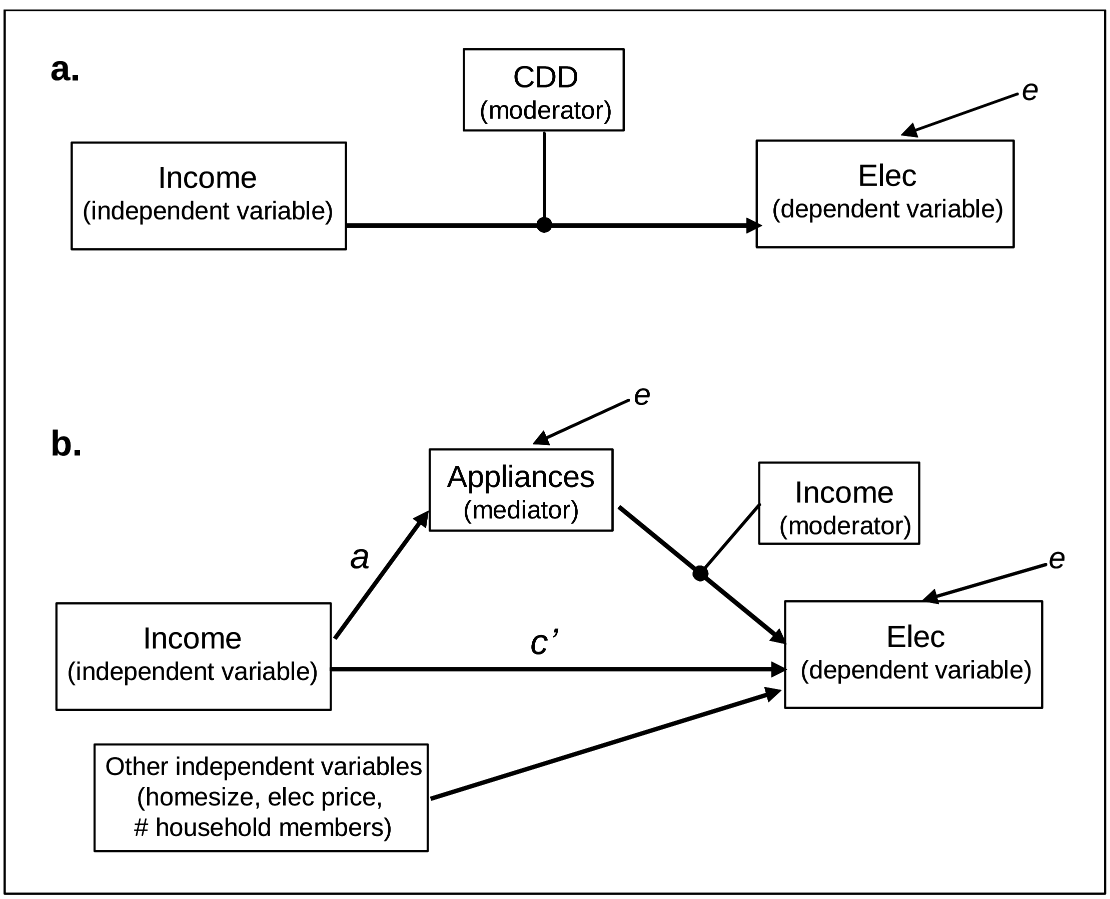


Figure 2b can also be represented by a pair of regression equations, where the first equation is the same as in the simple mediation model but is repeated here:

$$\text{Appliances} = i + a\text{*Income} + e \qquad (2)$$

However, the second equation now reflects the addition of moderation (to Equation 3 of the previous mediation model)[20]:

$$\text{Elec} = i + c'\text{*Income} + b_1\text{*Appliances} + b_2\text{*(Appliances*Income)} + d_1\text{*Sqft} + d_2\text{*Price} + d_3\text{*People} + e \qquad (5)$$

The moderated mediation model is now tested by considering the statistical significance of $a*b_2$ (see Figure 2b) and again noting that the pathway represented by *c*' should be smaller compared to the simple relationship between income and electricity consumption (*c* in Equation 1 above). Bootstrapping is employed to consider the statistical significance of $a*b_2$.

Results

Regression results generally support the hypothesized models, and estimations of the equations explained above are listed in Table 1 (see Appendix 1). Although heteroskedasticity exists in the data, White's test confirms that all but one regression coefficients are non-zero.[21] In the most basic model, I find that higher levels of income do predict higher electricity consumption, at the level indicated in Figure 3a below. The adjusted R-square of this regression equation is 0.3969, indicating that a moderate share of the electricity consumption variability is explained by household income and the three other demand variables, when appliances are not included as a variable. From the perspective of developing a better model of demand, the price indicator for electricity could be revisited to consider its nonlinear, tiered nature.

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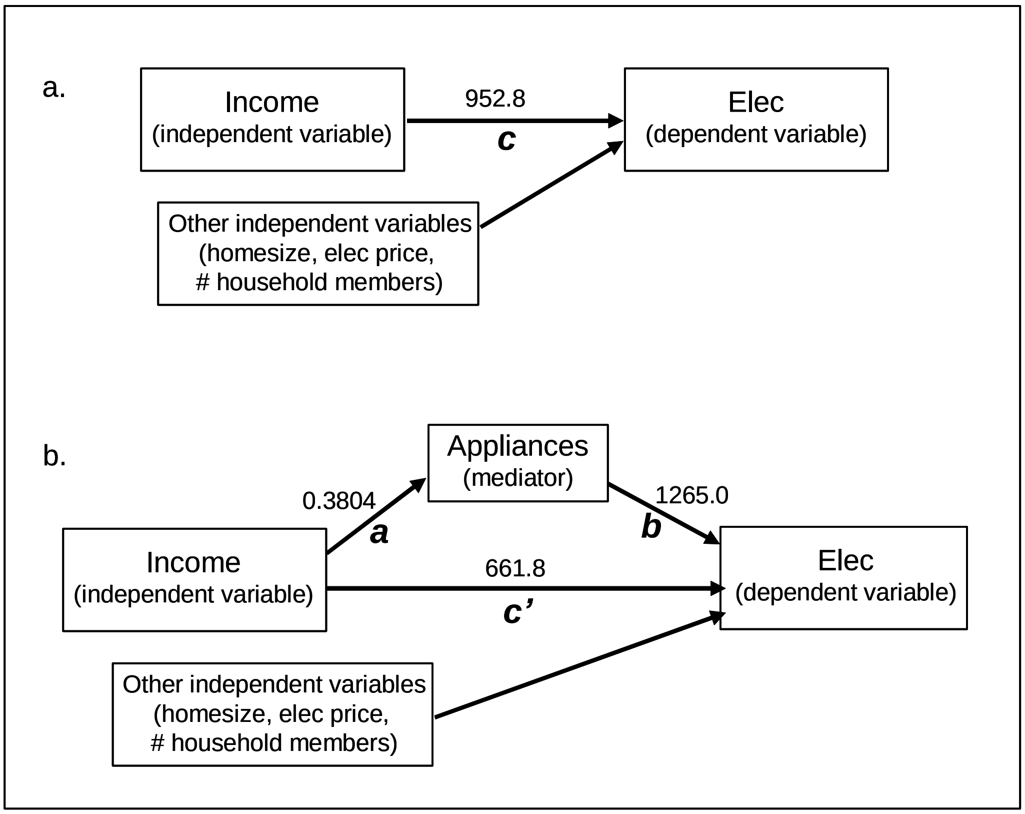
[20] Although the notation used here repeats the coefficient *c*', it is NOT to imply that the coefficient should be exactly the same as in Equation 3, but rather to suggest that there is a parallelism between Equation 3 *c*' and Equation 5 *c*' in that for both cases, the path represented by *c*' should have a lesser role compared to coefficient *c* in Equation 1 because of the presence of a mediating pathway. Repeated use of the coefficients b_1, b_2, d_1, d_2 and d_3 also does not imply equivalency to their earlier use but is strictly for notational simplicity.

[21] The coefficient for Income in the moderated mediation model fails White's test; see Table 1.

Regression equation results for the model that entertainment appliances mediate the impact of income on electricity consumption are also reported in Table 1 and Figure 3. Note that the direct influence of income on electricity consumption is smaller in Figure 3b (c') than Figure 3a (c) as is expected under mediation.

Figure 3. Two models of the influence of income on electricity consumption



In simpler models the pathway represented by a*b can be statistically tested by using Sobel's Method.[22] However, with heteroskedasticity biasing estimates, I instead use bootstrapping to consider the statistical significance of the a*b pathway. In 1000 iterations (see Figure 4 below for results), the value of a*b has a mean value of 480.7 and a minimum value of 364.6, which provides very solid evidence that this mediating pathway is positive and significant. From these results, it can also be estimated that the mediating pathway accounts for over 30% of the effect

[22] The standard error of a*b or se_{ab} is calculated as $se_{ab} = \sqrt{b^2 s_a^2 + a^2 s_b^2 + s_a^2 s_b^2}$

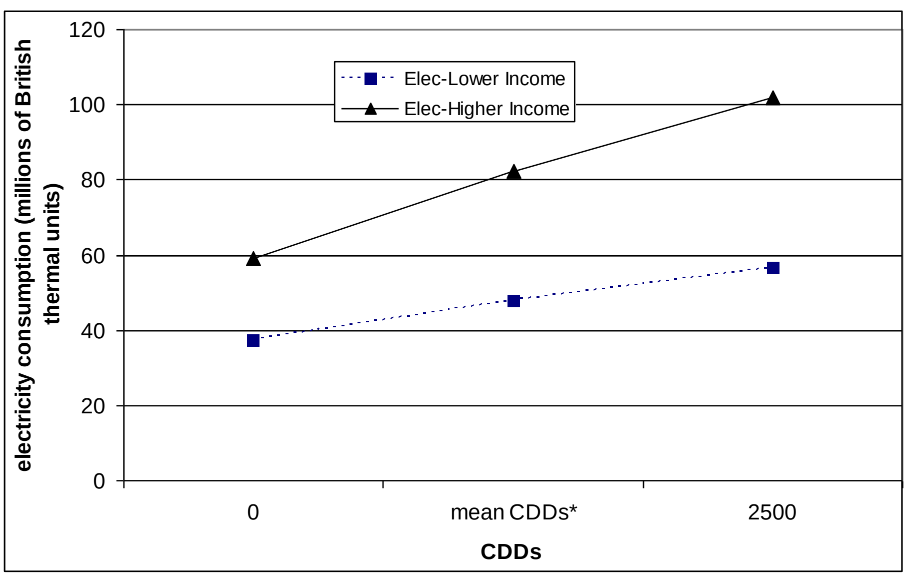
that income has on electricity consumption, assuming that additional explanatory variables or mediating pathways have not been overlooked or excluded.[23]

Figure 4. Bootstrapping results to test the *a*b* pathway of the mediation model

N	Mean	Std Dev	Minimum	Maximum
1000	480.7475593	41.5177464	364.5581995	599.4416956

The third model tested is a simple moderation model that air cooling needs, represented by CDDs, moderates household electricity consumption in single family detached homes. Results presented in Table 1, which reflect testing with centered data, support this conclusion and are pictured graphically below in Figure 5. From Figure 5, one can see that at higher levels of income, electricity consumption increases even more steeply with increasing air cooling needs. The effect may appear subtle but the additional electricity used by a higher income household moving from mean to high CDDs (to be precise, from 1362 to 2500 CDDs) represents about 10% of high income household electricity use (exclusive of space and water heating), or 20% in a low income household at 2500 CDDs.

Figure 5. Electricity consumption varying by income and CDDs



*mean CDDs=1362

[23] The R-squares are only moderate suggesting further explanatory components to the model might be possible; in addition, it is possible that income is mediated by other pathways in addition to appliances. The income effect could also be mediated by home size, for example.

The final results are for a model of moderated mediation, wherein income influences the presence of home entertainment appliances and moderates the level of their use. The regression results for Equation 5 are presented at the bottom of Table 1. Recall that in the case of moderated mediation, we are interested in the statistical significance of $a*b_2$, and whether we can be reasonably certain that this is nonzero. Here again, bootstrapping (1000 iterations) is used to consider the statistical significance of $a*b_2$ with results presented below in Figure 6 indicating that this pathway is nonzero at a 95% confidence level (only the first, minimum value is negative).

Figure 6. Bootstrapping results to test the $a*b_2$ pathway of the moderated mediation model

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   N            Mean         Std Dev         Minimum         Maximum
ƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒ
1000      40.1460663      14.4286905      -2.1938208      86.7498523
ƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒ
    Minimum and second 2 lowest observations:
                Obs       A*B2

                  1    -2.1938
                  2     2.5342
                  3     3.8198
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Conclusion

This study has combined the relational framework of mediation with an econometric view of residential electricity demand using government survey data. The results reported here that the household presence of entertainment appliances mediates the effect of income on electricity use and is further moderated by income levels has implications for policy makers. If increased energy efficiency or demand-side management are policy goals, then a deeper understanding of the drivers of energy, or specifically electricity, consumption could contribute to more informed or more efficient policies. For example, targeting higher income households with electricity efficiency campaigns could be a more effective use of limited resources than generic efforts across all households. In fact, using the modeling ideas presented here, one could further develop estimates of the impact that changes in appliance ownership and use would have on electricity consumption. To do so robustly would require that the mediation pathways modeled here first be imbedded into a more fulsomely developed model of residential electricity consumption.

References

Apte, J. and D. Arasteh (2008) Window-related energy consumption in the US residential and commercial building stock. Lawrence Berkeley National Laboratory, University of California. LBNL-60146. http://repositories.cdlib.org/lbnl/LBNL-60146

Energy Information Administration (EIA), Electric Power Annual 2006, www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html, viewed July 22, 2008.

EIA, Electric Power Monthly, www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html, Table 4.1, viewed July 28, 2008.

EIA, International Energy Annual, 2005, www.eia.doe.gov/pub/international, viewed July 21, 2008.

EIA, Residential Energy Consumption Survey, www.eia.doe.gov/emeu/RECS, viewed July 21, 2008.

EIA, World Energy Use and Carbon Dioxide Emissions, 1980-2001, May 2004, www.eia.doe.gov/emeu/cabs/carbonemiss/index.html, viewed July 21, 2008.

Ewing, Reid and Rong, Fang, "The impact of urban form on U.S. residential energy use," Housing Policy Debate (2008) 19:1.

Fisher, Frank M. and Kaysen, Carl, A Study in Econometrics: The Demand for Electricity in the United States, North Holland Publishing, Amsterdam (1962).

MacKinnon, David P., Introduction to Statistical Mediation Analysis, Lawrence Erlbaum Associates, New York (2008).

Narayan, Paresh K.; Smyth, Russell; and Prasad, Arti; "Electricity consumption in G7 countries: A panel cointegration analysis of residential demand elasticities;" Energy Policy (2007) 35: 4485-4494.

Reiss, Peter C. and White, Matthew W., "Household electricity demand, revisited," NBER Working Paper Series, Working Paper 8687, www.nber.org/papers/w8687, viewed July 1, 2008.

APPENDIX 1

Table 1. Regression Results
(Model numbers correspond to Figure numbers; n=4822 unless otherwise noted; reported p-values are for two-tailed test)

Model 1a.

Equation 1: Elec = $i + c$*Income + d_1*Sqft + d_2*Price + d_3*People + e

Global F-value: 794.07 Pr > F: <.0001 adj. R^2: 0.3969

parameter	estimate	standard error	t-value	P > |t|
Intercept	16900	720.40808	23.46	<.0001
Income	952.83893	76.73510	12.42	<.0001
Sqft	5.07017	0.21021	24.12	<.0001
Price	-489381	17981	-27.22	<.0001
People	2758.36236	115.42627	23.90	<.0001

Model 1b.

Equation 2: Appliances = $i + a$*Income + e

Global F-value: 761.38 Pr > F: <.0001 adj. R^2: 0.1362

parameter	estimate	standard error	t-value	P > |t|
Intercept	2.28065	0.09035	25.24	<.0001
Income	0.38040	0.01379	27.59	<.0001

Equation 3: Elec= $i + c'$*Income + b*Appliances + d_1*Sqft + d_2*Price + d_3*People + e

Global F-value: 731.53 Pr > F: <.0001 adj. R^2: 0.4311

parameter	estimate	standard error	t-value	P > |t|
Intercept	14933	709.14572	21.06	<.0001
Income	661.82197	76.45924	8.66	<.0001
Appliances	1265.03208	74.22286	17.04	<.0001
Sqft	4.35141	0.20847	20.87	<.0001
Price	-472154	17493	-26.99	<.0001
People	2198.47893	116.82056	18.82	<.0001

Model 2a. (n=2935 representing single family detached homes; centered data)

Equation 4: Elec = $i + b_1$*Income + b_2*CDD + b_3*(Income*CDD) + e

Global F-value: 266.68 Pr > F: <.0001 R^2: 0.214429

parameter	estimate	standard error	t-value	P > |t|
Intercept	34524.48956	326.2518619	105.82	<.0001
Income	2710.09566	143.2747344	18.92	<.0001
CDD	6.55454	0.3375657	19.42	<.0001
Income *CDD	1.17647	0.1517964	7.75	<.0001

[*continued*]

Table 1. Regression Results, *continued*

Model 2b.

Equation 2: Appliances = i + a*Income + e [*results above*]

Equation 5: Elec= i + c'*Income + b_1*Appliances + b_2*(Appliances*Income) + d_1*Sqft + d_2*Price + d_3*People + e

Global F-value: 613.74 Pr > F: <.0001 R^2: 0.4334

parameter	estimate	standard error	t-value	P > |t|
Intercept	17704.5856	1015.32190	17.44	<.0001
Income	229.6292	136.74945	1.68	0.0932*
Appliances	550.7658	201.61144	2.73	0.0063
Income*Appliances	105.7290	27.75354	3.81	0.0001
Sqft	4.2554	0.20970	20.29	<.0001
Price	-471941.5224	17468.38141	-27.02	<.0001
People	2232.6318	117.00099	19.08	<.0001

* Reported p-values are two-tailed and Income is hypothesized to have a positive relationship with electricity consumption. Although for a one-tailed test this reported p-value would be divided by 2, this estimate fails a White's test to be significantly different from zero when adjusting for heteroskedasticity.