Recent evidence on residential electricity consumption determinants: a panel two-stage least squares analysis, 2002-2005

Richard J. Cebula
Armstrong Atlantic State University

Nate Herder
Armstrong Atlantic State University

Abstract.

This empirical study seeks to provide evidence identifying key factors that have influenced the per capita consumption of electricity in the U.S. during recent years. This empirical analysis takes the form of P2SLS (panel two-stage least squares) estimations. State-level data are adopted for the four-year period from 2002 through 2005. The P2SLS findings indicate that the consumption of electricity per capita is an increasing function of cooling degree days, real personal disposable income, and the real price of natural gas, while being a decreasing function of the real unit price of electricity, and the extent of usage of natural gas for residential heating, as well as the degree to which each state has pursued energy efficiency policies.

Keywords: Residential electricity consumption, Electricity prices, Natural gas prices, Income, Cooling degree days, Natural gas usage, Energy efficiency policies

Introduction

Under the rubric of environmental economics, an extensive empirical literature concerned with energy consumption has developed during the last four decades. A significant component of this literature is concerned with the consumption of electricity, including the residential consumption thereof (Taylor, 1975; Garbacz, 1983; Dodgson, Millward, and Ward, 1990; Harris and Liu, 1993; Holtedahl and Joutz, 2004; Kamerschen and Porter, 2004; Moral-Carcedo and Vicens-Otero, 2005; Zachariadis and Pashourtidou, 2007; Horowitz, 2007). The residential consumption of electricity in the U.S. may continue to rise as the population continues to increase, especially if claims of global warming are correct (Harris and Liu, 1993; Energy Information Administration, 2006), making it all the more important for both policymakers and energy firms to monitor the factors influencing that consumption.

The present study focuses on identifying key economic factors and other conditions that have influenced the per capita residential consumption of electricity in the U.S. during recent years. The study also investigates the impact on per capita residential electricity consumption of the degree to which each state has pursued energy efficiency policies. Thus, the question of whether state energy-efficiency policies work is integrated into the present analysis.

Unlike most previous studies, this study uses a state-level panel data set for the period 2002 through 2005. By focusing on this time period, the evidence provided in this study is relatively current. The panel consists of the 48 contiguous states, with Washington, D.C. data included within the state of Maryland data set. The next section of this study provides the initial framework for the analysis, whereas subsequent section provides the P2SLS (panel two-stage least squares) estimates based on that initial framework. Several P2SLS estimations of an expanded version of the basic model are found in a second empirical section. The closing section of this study summarizes the findings of the study.

Initial Framework: An Eclectic Model

The analysis in principle initially follows Dodgson, Millward, and Ward (1990), Harris and Liu (1993), Holtedahl and Joutz (2004), Kammerschen and Porter (2004), Moral-Carcedo and Vicens-Otero (2005), Zachariadis and Pashourtidou (2007), Horowitz (2007) and others in modeling residential electricity consumption as a function of a number of essentially demand-driven forces.

The eclectic model of residential electricity consumption is initially expressed as follows:

$$QCjt = f(CDDjt, ELPRjt, INCjt, NATGASPRjt, NATGASHEATjt) \quad (1)$$

where (data source in parentheses):
QCjt = the total consumption of residential electricity per capita, measured as the ratio of total *residential* electricity consumption in state j in year t as a percentage of the total population in state j in year t (Electric Power Annual, 2006);
CDDjt = total annual number of cooling degree days in state j in year t (National Climatic Data Center, 2008);
ELPRjt = the average price of residential electricity in state j in year t, measured in cents per kilowatt hour (Electric Power Annual, 2006), scaled by the state cost of living index for state j in year t (ACCRA, 2005);

INCjt = per capita disposable income in state j in year t (U.S. Census Bureau, 2004, 2006, 2008, Table 660), scaled by the state cost of living index for state j in year t (ACCRA, 2005);
NATGASPRjt = the average price of natural gas in state j in year t, expressed in dollars per cubic foot to residential customers in state j in year t (Natural Gas Demand, 2009), scaled by the state cost of living index for state j in year t (ACCRA, 2005); and
NATGASHEATjt = the percentage of residences in state j in year t that were heated with natural gas (Natural Gas Demand, 2009).

Unlike most previous studies, this study uses a state-level panel for the U.S. for the period 2002 through 2005. The panel consists of the 48 contiguous states, with Alaska and Hawaii excluded as outliers. Washington, D.C. data are included in the study by being measured along the data for the state of Maryland, i.e., as part of the Maryland data set. Thus, j = 1,…48, and t = 2002, 2003, 2004, 2005. Several of the variables (ELPRjt, INCjt, NATGASPRjt) are scaled by the state cost of living index so as to make them comparable; such an adjustment was necessary, given the large interstate differentials in the overall cost of living (ACCRA, 2005).

The greater the number of cooling degree days (CDDjt), the greater the expected demand for/consumption of residential electricity to cool the interior of residential structures, *ceteris paribus* (Dodgson, Millward, and Ward, 1990; Harris and Liu, 1993; Kamerschen and Porter, 2004; Holtedahl and Joutz, 2004; Moral-Carcedo and Vicens-Otero, 2005; Horowitz, 2007). Following the "conventional wisdom," it is expected that the higher the unit price of residential electricity (ELPRjt), the lower the consumption of same, *ceteris paribus* (Dodgson, Millward, and Ward, 1990; Harris and Liu, 1993; Holtedahl and Joutz, 2004). As represented in other related studies, residential electricity is treated as a "normal good" (Dodgson, Millward, and ward, 1990; Harris and Liu, 1993; Holtedahl and Joutz, 2004). Thus, the effect of a higher per capita real disposable income (INCjt) on electricity consumption is hypothesized to be positive, *ceteris paribus*. Natural gas is clearly a substitute for electricity in a variety of household applications, including cooking, hot water production, and home heating. Thus, it is expected that the higher the unit price of natural gas (NATGASPR), the greater the degree of substitution over time of electricity for natural gas, *ceteris paribus* (Dodgson, Millward, and Ward, 1990; Horowitz, 2007). Finally, the variable NATGASHEATjt is a measure of the degree to which natural gas is used in place of electricity to heat residences. The greater the degree to which this usage occurs, the lower the consumption of residential electricity, *ceteris paribus* (Dodgson, Millward, and Ward, 1990; Horowitz, 2007).

Thus, it is hypothesized that:

$$f_{CDD} > 0,\ f_{ELPR} < 0,\ f_{INC} > 0,\ f_{NATGASPR} > 0,\ f_{NATGASHEAT} > 0 \qquad (2)$$

Initial Empirical Estimations

Based on the model in (1) and (2), the following log-log model is to be estimated initially:

$$\log QCjt = a_0 + a_1 \log CDDjt + a_2 \log ELPRjt + a_3 \log INCjt + a_4 \log NATGASPRjt + a_5 \log NATGASHEATjt + \mu \qquad (3)$$

where a_0 is a constant, "log" indicates the natural log of a variable, μ is a stochastic error term, and estimated "coefficients" are elasticities.

Given that the quantity demanded of residential electricity (log QDjt) and the unit price of electricity (log ELPRjt) are contemporaneous, the possibility of simultaneity bias exists. Accordingly, the model in (3) is estimated by P2SLS, with the instrument being the one-year lag of the natural log of the GSP (gross state product) of state j, log GSPjt-1 (U.S. Census Bureau, 2004, 2006, 2008). The choice of this variable as the instrument was based on the finding that it was highly correlated with ELPRjt while not being correlated with the error terms in the system.

The P2SLS estimation of equation (3), adopting the White (1980) heteroskedasticity correction, is:

$$\log QCjt = 5.69 + \underset{(+42.43)}{0.192} \log CDDjt - \underset{(-7.08)}{0.788} \log ELPRjt + \underset{(+9.89)}{0.24} \log INCjt$$

$$+ \underset{(+11.87)}{0.23} \log NATGASPRjt - \underset{(-12.26)}{0.03} \log NATGASHEATjt, \; F = 131.609 \qquad (4)$$

where terms in parentheses are t-values.

In estimate (4), all five of the estimated elasticities exhibit the expected signs and are statistically significant at the one percent level. The F-statistic is statistically significant at far beyond the one percent level, attesting to the overall strength of the model. Thus, the P2SLS estimate implies that the log of per capita residential electricity consumption is an increasing function of the log of the number of cooling degree days, the log of real per capita disposable income, and the log of the real unit price of natural gas. Furthermore, the log of per capita residential electricity consumption is a decreasing function of the log of the real unit price of electricity and the log of the percentage of residences heated by natural gas.

The result for the variable log CDDjt implies that a one percent increase in the annual number of cooling degree days would elicit a 0.192 percent increase in per capita residential electricity consumption. The result for the variable log ELPRjt implies that a one percent increase in the real unit price of electricity would reduce per capita residential electricity consumption by 0.788 percent. As for the variable log INCjt, a one percent increase in real per capita disposable income would elevate per capita residential electricity consumption by 0.24 percent. Regarding the variable log NATGASPRjt, a one percent increase in the real unit price of natural gas would elicit a 0.23 percent increase in the per capita consumption of residential electricity consumption. Finally, the result for the variable log NATGASHEATjt implies that a one percent increase in the percentage of residences heated by natural gas would reduce per capita residential electricity consumption by 0.03 percent.

As shown in equation (5), if the model is estimated in semi-log form by P2SLS, using the White (1980) heteroskedasticity correction and using the one year lag of GSP (GSPjt-1) as the instrument, the results are qualitatively entirely compatible with those in equation (4):

$$\log QCjt = 9.47 + \underset{(+30.62)}{0.00017} \; CDDjt - \underset{(-10.95)}{8.839} \; ELPRjt + \underset{(+35.30)}{0.00072} \; INCjt$$

$$+ \underset{(+16.77)}{2.0002} \; NATGASPRjt - \underset{(-14.42)}{0.000005} \; NATGASHEATjt, \; F = 131.94 \qquad (5)$$

Based on the results in equation (5), the natural log of per capita residential electricity consumption is an increasing function of cooling degree days, per capita real disposable income, and the real unit price of natural gas, while being a decreasing function of the real unit price of residential electricity and the percentage of residences heated by natural gas. These semi-log P2SLS findings are in principle consistent with those in the log-log P2SLS estimate in equation (4), thereby affirming the robustness of the basic model.

Estimations of the Expanded Model

The basic model considered above can be expanded. Perhaps the most interesting expansion of that model would be to investigate the impact on per capita residential electricity consumption of the level of state government involvement in the establishment and perpetuation of energy efficiency programs (Horowitz, 2007). Such a measure is provided by a LEEP score, where the term "LEEP" stands for **L**evel of **E**nergy **E**fficiency **P**rograms (DSIRE Solar, 2009). To accomplish this extension, this study adopts this cardinal measure (1, 2, 3) reflecting whether a given state j in year t was weakly (LEEP =1), moderately (LEEP = 2), or strongly (LEEP = 3) engaged in energy efficiency program activities. It is hypothesized that the stronger a state government's commitment to energy efficiency programs, i.e., the higher its LEEP score, the lower the per capita consumption of residential electricity in the state, *ceteris paribus*.

Integrating the LEEP score into the basic model in equation (3) and the semi-log version thereof, yields the following models:

$$\log QCjt = a_0 + a_1 \log CDDjt + a_2 \log ELPRjt + a_3 \log INCjt + a_4 \log NATGASPRjt + a_5 \log NATGASHEATjt + a_6 \log LEEPjt + \mu' \quad (6)$$

$$\log QCjt = a_0 + a_1\, CDDjt + a_2\, ELPRjt + a_3\, INCjt + a_4\, NATGASPRjt + a_5\, NATGASHEATjt + a_6\, LEEPjt + \mu'' \quad (7)$$

where LEEPjt is the cardinal LEEP score for state j in year t.

The P2SLS estimations of equations (6) and (7), adopting the White (1980) heteroskedasticity correction, yield equations (8) and (9), respectively:

$$\begin{aligned} Log\ QCjt = 4.056 &+ \underset{(+23.16)}{0.189}\ Log\ CDDjt - \underset{(-14.95)}{1.268}\ Log\ ELPRjt + \underset{(+6.63)}{0.432}\ Log\ INCjt \\ &+ \underset{(+9.23)}{0.239}\ Log\ NATGASPRjt - \underset{(-7.79)}{0.051}\ Log\ NATGASHEATjt \\ &\underset{(-4.68)}{-0.071}\ Log\ LEEPjt,\ F = 131.87 \end{aligned} \quad (8)$$

$$\begin{aligned} Log\ QCjt = 9.543 &+ \underset{(+30.03)}{0.000167}\ CDDjt - \underset{(-17.48)}{9.642}\ ELPRjt + \underset{(+18.59)}{0.0.00082}\ INCjt \\ &+ \underset{(+15.85)}{1.973}\ NATGASPRjt - \underset{(-7.79)}{0.0000053}\ NATGASHEATjt \end{aligned}$$

$-0.00545 \text{ LEEPjt}, F = 139.164$ (9)
(-5.78)

In estimations (8) and (9), all of the estimated elasticities and coefficients exhibit the expected signs and are statistically significant at the one percent level. Thus, once again, there is strong empirical evidence that per capita residential electricity consumption is positively impacted by cooling degree days, real personal income per capita, and real natural gas prices, while being negatively impacted by real electricity prices and the percentage of residences heated with natural gas. Furthermore, in both the log-log and semi-log P2SLS estimates, there is compelling evidence that stronger state government involvement in the establishment and perpetuation of energy efficiency programs helps to at least some degree to reduce per capita residential electricity consumption. For example, in equation (8), it appears that a one percent increase in the state commitment to energy efficiency programs reduces per capita residential electricity consumption by 0.071 percent.

Finally, there is the issue of whether inclusion of a trend variable affects the results, given that the study period covers a four-year time span. To test for this, equations (6) and (7) were re-estimated by P2SLS with a linear trend variable, TREND, included. The results are found in equations (10) and (11):

Log QCjt = 4.02 + 0.187 Log CDDjt - 1.244 Log ELPRjt + 0.414 Log INCjt
(+22.82) (-14.21) (+6.19)

+ 0.236 Log NATGASPRjt - 0.05 Log NATGASHEATjt
(+9.18) (-7.70)

-0.069 Log LEEPjt + 0.0003 TREND, F = 132.05 (10)
(-4.20) (+2.00)

Log QCjt = 9.255 + 0.000162 CDDjt - 9.633 ELPRjt + 0.0.00081 INCjt
(+29.92) (-17.39) (+18.15)

+ 1.966 NATGASPRjt - 0.0000052 NATGASHEATjt
(+15.78) (-7.76)

-0.00541 LEEPjt + 0.00004 TREND, F = 140.42 (11)
(-5.71) (+1.99)

Clearly, the findings in equations (10) and (11) are effectively unchanged from the findings in equations (8) and (9), respectively. The variable TREND is statistically significant at the five percent level in both (10) and (11), suggesting that its inclusion in the model is appropriate. However, the results for all of the other estimators in equations (10 and (11), by being so similar to their counterparts in equations (8) and (9), imply that the TREND variable is not a critical component of the model. Regardless of whether the TREND variable is included, the conclusions of the analysis remain very consistent.

V. Conclusion

This empirical study investigates recent evidence on determinants of per capita residential electricity consumption in the U.S. Panel two-stage least squares estimates for the period 2002 through 2005 of both log-log and semi-log specifications consistently provide strong empirical findings. In particular, it is found that per capita residential electricity consumption is an increasing function of the number of cooling degree days, real per capita disposable income, and the real unit price of natural gas. It also is a decreasing function of the real unit price of residential electricity and the percentage of residences heated by natural gas, as well as the degree to which each state has pursued energy efficiency policies. The latter finding provides hope that intelligent public policy can potentially be beneficial to the environmental challenges presented by residential electricity needs.

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