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Trends in Regional U.S. Electricity and Natural Gas Price Elasticity

1022196

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Technical Update, November 2010

EPRI Project Manager

V. Niemeyer

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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ACKNOWLEDGMENTS

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

Christensen Associates Energy Consulting
800 University Bay Drive, Suite 400
Madison, WI 53705

Principal Investigators
S. Braithwait
D. Hansen

This report describes research sponsored by EPRI.

We wish to acknowledge both Chris Schlegel and Ally Hung of Southern Company, for their encouragement, invaluable review, and critique of earlier drafts of this work.

This publication is a corporate document that should be cited in the literature in the following manner:

Trends in Regional U.S. Electricity and Natural Gas Price Elasticity. EPRI, Palo Alto, CA: 2010. 1022196.

ABSTRACT

The extent to which consumers are likely to alter energy consumption in response to energy price changes continues to be a critical element in energy policy analysis. Notably, climate change policies that are expected to increase the price of electricity will engender different consequences for the power industry, state economies, and power users, depending on how consumers respond to those prices. Understanding and acknowledging such impacts will be critical to the proper implementation of such policies in the future. This new analysis of consumer responsiveness to energy price changes updates our understanding to include the recent period of rising prices since 2000.

Many statistics cited today about consumer price responsiveness were developed in the 1980s and early1990 in the wake of substantial price increases in the late 1970s and early 1980s. More recent studies have analyzed data over the 1990s. Because this decade was a period of generally *declining* real (inflation adjusted) electricity prices in the United States, comparisons with earlier studies are difficult.

The data used in this analysis include several recent years of rising electricity prices near the end of the time period through 2007, thus allowing an assessment of trends in price responsiveness during a period of price *increases*. The analysis considers total demand for electricity and natural gas, as well as residential demand for electricity, at both national and regional levels. This breakdown is consistent with EPRI's interest in aggregate measures of price responsiveness for use in broad studies of potential effects of climate change legislation.

Keywords

Elasticity
Price responsiveness
Electricity demand
Natural gas demand
Climate change policy

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TRENDS IN REGIONAL US ELECTRICITY AND NATURAL GAS PRICE ELASTICITY

Introduction

How customers respond to changes in energy prices remains a critical element of many energy policy analyses and debates, and current discussions concerning alternative climate change policies are no exception. Policies that increase the price of electricity will impose different effects on the power industry and state economies depending on how consumers respond.

A number of studies of customer price responsiveness (a measure called price elasticity[1]) were undertaken in the 1980s and early 1990s, following substantial price increases in the late 1970s and early 1980s.[2] A few studies of electricity demand (summarized in Appendix A below) have been undertaken recently, but the estimated price elasticities generally represent consumers' response to *declining* real (inflation adjusted) electricity prices experienced in the U.S. during the late 1980s and 1990s. Prices in many states have increased since 2000, particularly after 2004, largely driven until recently by increased costs of natural gas and other commodity prices.

This study reports results of an analysis of short-run and long-run price elasticities of demand for electricity and natural gas, by Census region in the U.S., for a period that includes these recent price increases. The analysis considers total and residential electricity demand, and total natural gas consumption, at both the national and regional levels. This breakdown is consistent with EPRI's interest in aggregate price elasticities for use in broad studies of potential effects of climate change legislation. The study results are presented, and compared against several of the recent studies described in Appendix A.

Data Sources and Trends

The data used in the analysis include energy consumption and average revenue (price) statistics for 1993 through 2007 from the Department of Energy's Energy Information Administration (EIA).

Electricity prices (dotted blue line) generally declined over the first part of this period and have risen over the past few years, as illustrated for the total US in Figure 1-1. This chart shows real electricity price (average revenue), total sales per customer, and real per capita disposable

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[1] *Price elasticity* is defined as the percentage change in consumption (*e.g.*, of electricity) for a given percentage change in price, while controlling for changes in other influencing factors such as weather and economic growth. *Short-run price elasticity* reflects consumers' changes in consumption within three to five years following a price change, while *long-run price elasticity* reflects usage changes after many years have passed, by which time changes in the efficiency of energy-using devices, such as lighting, motors, and household appliances can be made.

[2] "Customer Response to Electricity Prices: Information to Support Wholesale Price Forecasting and Market Analysis," EPRI, Palo Alto, CA: 2001 (Contractor: Christensen Associates Energy Consulting).

personal income, from 1993 through 2007. Per capita income (dashed green line) rose throughout the period, at a rate of approximately 2 percent, with only a few noticeably larger or smaller than average annual changes. Total sales per customer (solid pink line) grew at an average annual rate of about 1 percent through 2000, during which time the national average real electricity price fell at a rate of about 2 percent. Since that point, the average price has risen at an average annual rate of just under 2 percent, including particularly steep increases in 2001 and in the last three years of the period. Sales per customer fell substantially in 2001 and then grew at less than half the rate in the 1990s.

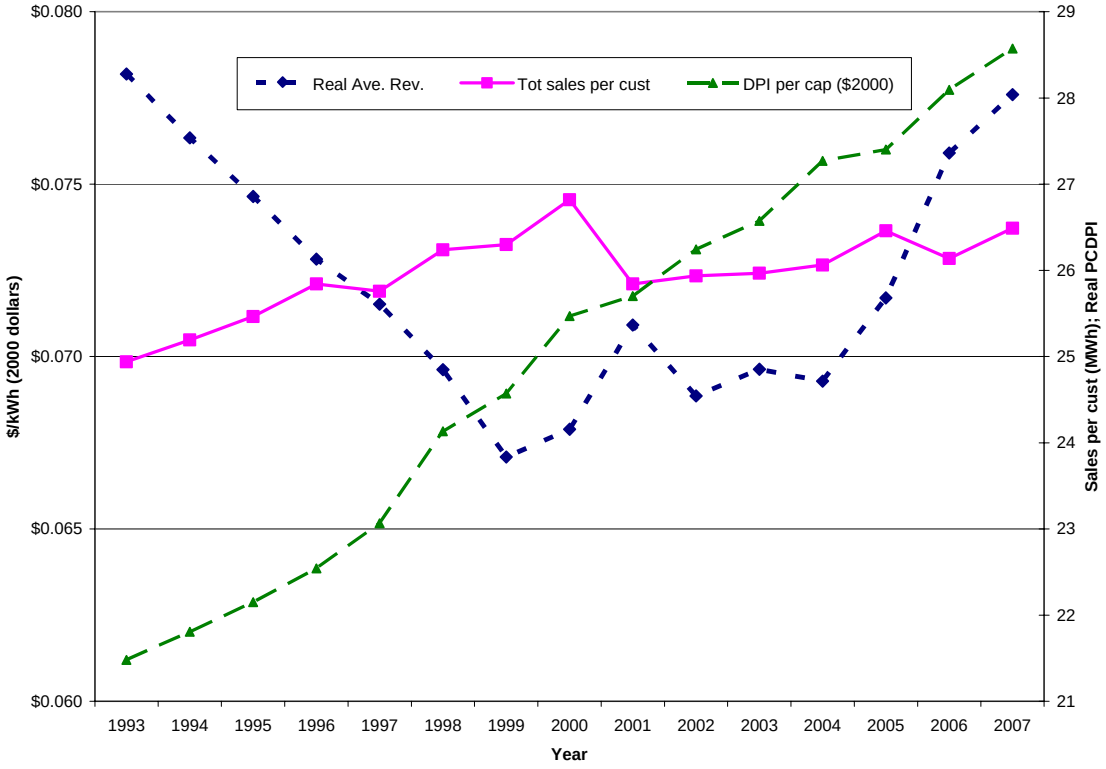

Figure 1-1
National-Level Real Electricity Prices ($2000) and Sales per Customer

The patterns of electricity prices and sales in individual states were more diverse, due to a variety of factors including differences in the mix of generation capacity, the timing of rate cases, and the status and timing of retail deregulation in some states, which was sometimes combined with temporary retail rate freezes.

Electricity Results

The methodology of elasticity estimation is in general well developed and well understood. For this study statistical models were estimated, using the data described above, for total electricity

sales and residential sales.[3] The total sales model was estimated using data in two alternative forms – aggregate and per customer. The residential model was estimated in per-customer form only. In all cases both a national model including all states (labeled "US" in the table below), and regional models for each of eight census regions were estimated. Price elasticity for each of the models is shown in Table 1-1, along with results reported in studies conducted by the RAND Corporation[4] and Metcalf.[5] Appendix 1 below provides a more comprehensive summary of these and other alternative studies.

Most (though not all) of the models produced negative price elasticity within normal ranges, as expected. One notable result is the very high elasticity estimated for the Pacific region for the total sales models. A likely reason for this is the large retail price increases that occurred beginning in 2001 in each of the states in that region (California, Oregon and Washington) due to the now infamous California energy crisis, and the substantial reduction in non-residential sales that occurred as a result.

Table 1-1
Alternative estimates of electricity price elasticity

	Current Study (CAEC)						RAND Study		Metcalf	
	Total Electricity Sales		Electricity Sales per Customer		Residential Total Electricity Sales		Residential Sales (RAND)		Total Electricity Sales	
	1993-2007		1993-2007		1993-2007		1977-2004		1970-2001	
Region	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
US	-0.12	-0.41	-0.13	-0.42	-0.10	-0.29	-0.24	-0.32	-0.11	-0.30
New England (NE)	-0.08	-0.22	-0.06	-0.19	-0.14	-0.37	-0.19	-0.28	-0.10	-0.23
Middle Atlantic (MA)	-0.12	-0.17	-0.11	-0.12	-0.06	-0.09	-0.23	-0.24		
EN Central (ENC)	0.01	0.03	-0.02	-0.07	-0.07	-0.08	-0.05	-0.05	-0.03	-0.08
WN Central (WNC)	-0.11	-0.23	-0.09	-0.24	-0.05	-0.08	-0.17	-0.27		
South Atlantic (SA)	-0.13	-0.39	-0.16	-0.33	-0.11	-0.25	-0.31	-0.32		
ES Central (ESC)	-0.13	-0.21	0.00	0.00	-0.27	-0.26	-0.26	-0.58	-0.07	-0.26
WS Central (WSC)	-0.03	-0.12	-0.08	-0.22	-0.07	-0.13	-0.13	-0.19		
Mountain (Mtn)	-0.20	-0.58	-0.20	-0.44	-0.09	-0.35	-0.21	-0.22	-0.05	-0.12
Pacific (Pac)	-0.53	-0.96	-0.47	-1.04	-0.19	-0.33	-0.18	-0.23		

As further illumination of the regional results, Figure 1-2 illustrates the residential short-run price elasticity estimated in this study and by RAND, where the values shown suppress the negative signs for clarity. The results appear qualitatively similar for several of the regions, although the RAND results are generally larger in absolute value at both the national level and for several regions. Metcalf's results (in Table 1-1) are similar to this study's results at the national level, but are generally smaller at the regional level.

[3] The details of the chosen functional forms and equation specifications are summarized in Appendix 2 below.

[4] Mark A. Bernstein and James Griffin, *Regional Differences in the Price-Elasticity of Demand for Energy*, RAND Corporation, 2005.

[5] Gilbert Metcalf, "An Empirical Analysis of Energy Intensity and Its Determinants at the State Level," *The Energy Journal*, Vol. 29, No. 3, 2008.

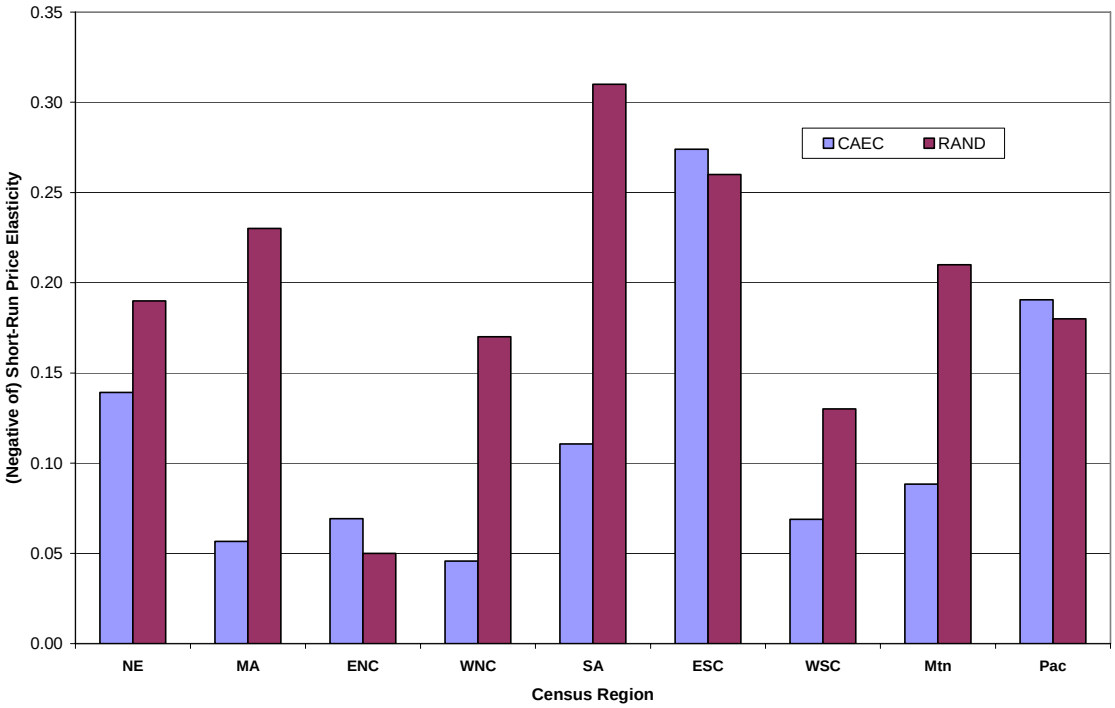

Figure 1-2
Short-run residential electricity price elasticity by region – This Study (CAEC) and RAND (negative signs have been suppressed for clarity)

The Effect of Recent Rising Prices

To test the extent to which these estimated price elasticities may have been determined by the post-2000 price increases, a sensitivity analysis was performed on the model of total electricity sales per capita. The analysis involved extending the time series successively year by year beyond 2004 - the last data point of the RAND study - and re-estimating the model for each time period. At the national level, as shown in Figure 1-1 above, that time period was dominated by the large price increase in 2001 and the more gradual increases in the last three years of data (2005 – 2007). The 2001 price increase caused by the California crisis had relatively minor effects outside of the Pacific and Mountain regions.

Table 1-2 and Figure 1-3 illustrate the sensitivity results. The total US and several of the regions follow a similar pattern – the estimated elasticities for the different periods have similar magnitudes, but they are *largest* for the period that *excludes* the last three years of data, and *smallest* for the period that includes all the data through 2007. These results suggest caution in using price elasticity results estimated over the earlier period of largely falling prices, in that they could overstate the effect of the recent price increases, as well as of potential future price increases.[6]

[6] The financial crisis and subsequent economic slowdown in 2008 and to date in 2010 will strongly affect electricity consumption in the period immediately following the period included in this study.

Table 1-2
Effect of alternative time periods on estimated price responsiveness

Region	Total Electricity Sales per Customer							
	1993-2007		1993-2006		1993-2005		1993-2004	
	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
US	-0.13	-0.42	-0.18	-0.53	-0.22	-0.56	-0.26	-0.60
New England (NE)	-0.06	-0.19	-0.10	-0.32	-0.08	-0.21	-0.08	-0.20
Middle Atlantic (MA)	-0.11	-0.12	-0.13	-0.14	-0.07	-0.08	-0.08	-0.09
EN Central (ENC)	-0.02	-0.07	-0.04	-0.19	-0.04	-0.16	-0.08	-0.24
WN Central (WNC)	-0.09	-0.24	-0.19	-0.44	-0.26	-0.51	-0.35	-0.74
South Atlantic (SA)	-0.16	-0.33	-0.22	-0.45	-0.20	-0.37	-0.31	-0.57
ES Central (ESC)	0.00	0.00	-0.01	-0.02	0.01	0.01	0.02	0.03
WS Central (WSC)	-0.08	-0.22	-0.13	-0.30	-0.21	-0.40	-0.24	-0.46
Mountain (Mtn)	-0.20	-0.44	-0.26	-0.48	-0.30	-0.49	-0.36	-0.53
Pacific (Pac)	-0.47	-1.04	-0.48	-1.04	-0.48	-1.01	-0.44	-0.95

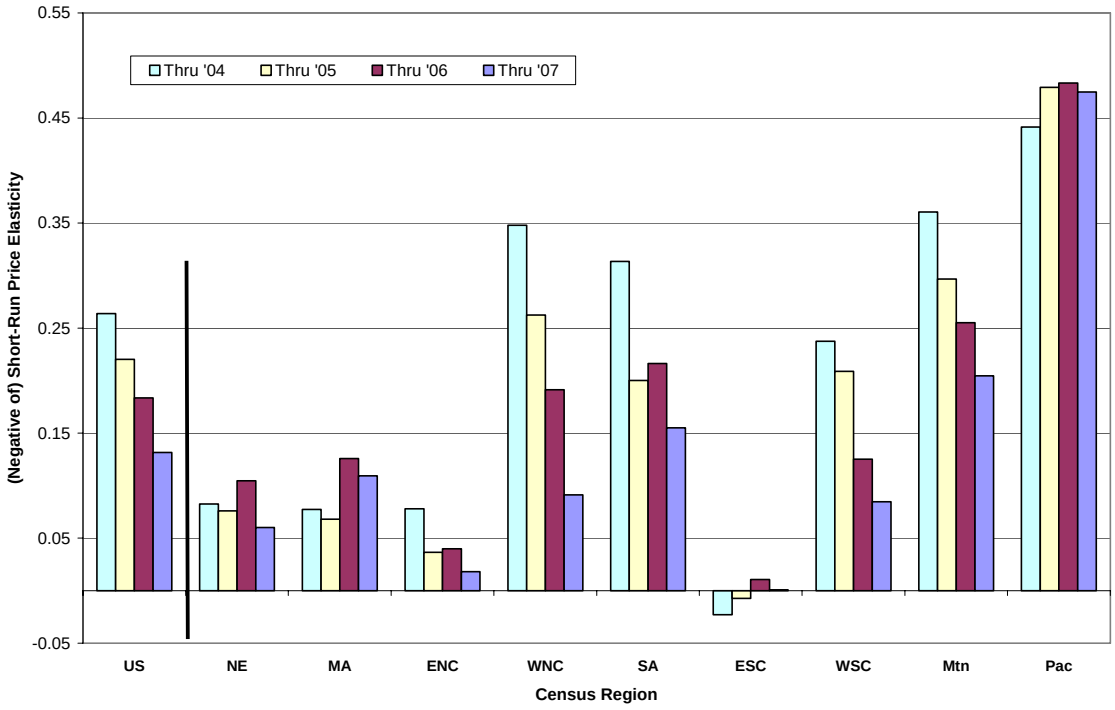

Figure 1-3
Effect of alternative time periods on short-run price elasticity
(illustrated as the *negative* of the values in Table 1-2)

Figure 1-4 below offers additional insight on the sensitivity of the elasticity estimates to the time period of analysis, as well as to the effect of the large price increases that impacted some Western states in 2000-01. It shows the result of estimating the national-level total sales per customer model repeatedly over increasingly lengthy time periods ending in 1999 through 2007,

as well as excluding the data for the states in the Pacific and Mountain regions.[7] The last point on the solid line represents the elasticity when including data for the entire period for all states. The remaining points on that line show the effect of estimating the model over progressively shorter time periods, by excluding years starting from the end of the time series. The estimated short-run price elasticity at the national-level is as large as 0.37 using only data through 2001, and falls as years after 2001 are added to the time series. In contrast, when the Pacific and Mountain region states are excluded from the analysis, the estimated price elasticities are more stable, varying only between about 0.10 and 0.17 in absolute value. These results suggest that price responsiveness in the Pacific and Mountain regions has differed substantially from that of the rest of the U.S. in recent years, and perhaps should be the subject of further study. They also suggest that price responsiveness exclusive of those regions has remained relatively stable through periods of both falling and rising electricity prices.

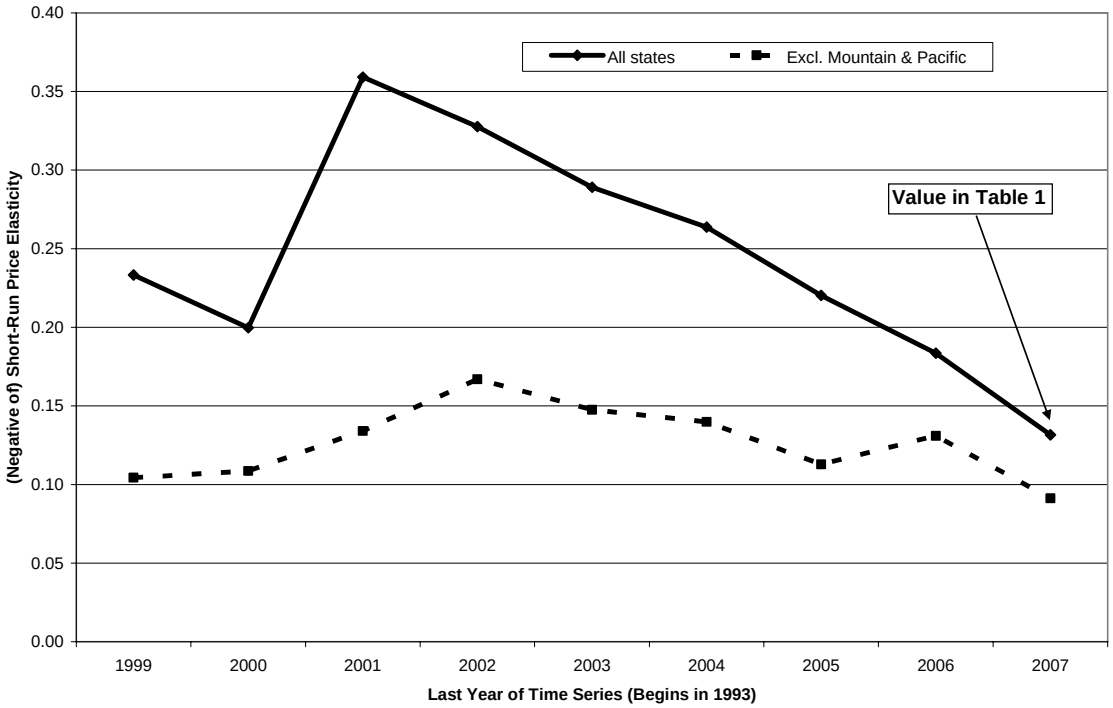

Figure 1-4
Total Electricity Sales Per Customer
Effect on national total short-run price elasticity of alternative time periods and excluding Pacific and Mountain regions

Natural Gas Results

As with electricity, the models of natural gas demand included all of the states (labeled "US" in the table below) as well as models by census region. The estimated price elasticities are shown in Table 1-3, along with results reported by the RAND study, which used data through 2004. Overall, the national and regional results appear reasonable, although there are some fairly large

[7] For clarity, the values plotted are the absolute values of the estimated short-run elasticity values estimated over the different periods. The negative signs are suppressed.

differences in some regions, likely due in part to differences in time periods and customer groups.

Table 1-3
Estimates of natural gas price elasticity

Region	Total Natural Gas		Residential	
	CAEC 1993-2006		RAND 1977-2004	
	Short-run	Long-run	Short-run	Long-run
US	-0.16	-0.58	-0.13	-0.31
New England	-0.40	-1.19	-0.13	-0.31
Middle Atlantic	-0.18	-0.36	-0.17	-0.34
EN Central	-0.13	-0.18	-0.12	-0.17
WN Central	-0.12	-0.43	-0.14	-0.22
South Atlantic	-0.22	-0.36	-0.07	-0.14
ES Central	-0.26	-0.42	-0.10	-0.25
WS Central	-0.25	-0.51	-0.05	-0.07
Mountain	-0.04	-0.16	-0.16	-0.36
Pacific	-0.07	-0.16	-0.16	-0.45

Conclusions

This study adds to recent investigations of price elasticity of electricity and natural gas by incorporating more recent data, which includes the recent period of price increases not observed in the prior studies.

The findings reflect reasonably consistent patterns of price response. At the national level, electricity price elasticity of -0.13 in the short run and -0.42 in the long run have been estimated. For natural gas, these values are -0.16 and -0.58, respectively. These results are broadly consistent with those of other recent studies, particularly a study conducted by RAND, using comparable state data, but only through 2004. The effect of including recent information covering a period of rising prices appears to be minimal.

A
SUMMARY OF RECENT STUDIES

Below are summarized the findings from four recent analyses of price elasticity for different types of energy. One of these studies (RAND, 2005) estimated a variety of demand equations for residential electricity and natural gas consumption, and commercial electricity consumption.[8] The RAND study was based on state-level data for 1977 to 2004. Results were reported for models developed at three levels of aggregation – national, regional, and state.

The second study (Metcalf, 2008) decomposed changes in state-level energy intensity into *efficiency* and *activity* indexes, and estimated regional price elasticity.[9] The third study (Reiss & White, 2005) used detailed household-level data for California, along with sophisticated modeling and analysis techniques to estimate residential customer price elasticity in the context of increasing-block rates.[10] The final study (Hughes, et al, 2008) dealt with the demand for gasoline, which is related but peripheral to EPRI's interest in electricity demand.[11] However its findings on differences in price elasticity in recent years when compared to an earlier period of rising prices may be instructive by analogy.

The RAND study used state-level data for 1977-2004 to estimate models at three levels of aggregation (national, regional, and state). Different interactive variables were used to either constrain the price elasticity coefficients to be the same for all states (national model), or allow them to vary by region or state. RAND's conclusions included the following:

1. At the *national* level, the estimated *residential* short-run and long-run price elasticities for electricity were -0.24 and -0.32 respectively.

2. Comparable estimates for the *commercial* sector were -0.21 and -0.97.

3. At the *regional* level, estimated *residential* short-run elasticities ranged from -0.13 to -0.32, while long-run elasticities ranged from -0.17 to -0.62. The most price responsive regions were South Atlantic, East South Central and Mid Atlantic, while least price responsive were West North Central, West South Central, and East North Central.

4. *Commercial* short-run elasticities ranged from -0.18 to -0.31, while long-run values ranged from -0.37 to -1.4 (the statistical significance was marginal however). The most elastic regions were Pacific Coast and East South Central, while the least responsive were Mountain, West North Central and South Atlantic.

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[8] Mark A. Bernstein and James Griffin, see footnote 4 above.
[9] Gilbert Metcalf, see footnote 5 above.
[10] Peter C. Reiss and Matthew W. White, "Household Electricity Demand, Revisited," *Review of Economic Studies*, 72, pp. 853-883, 2005.
[11] Jonathan Hughes, C.R. Knittel and Daniel Sperling, "Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand", *The Energy Journal*, Vol 29, No. 1, 2008.

The RAND study used a fairly standard log-linear equation, and included a lagged dependent variable to allow for the calculation of an implied long-run elasticity. However, it also included lagged values for *all* of the independent variables (*e.g.*, electricity price and natural gas price). The study also used a somewhat crude measure of weather – the *sum* of CDD and HDD - and constrained the weather *coefficient* to be the same for every region or state. Finally, over the time period of the data used in the analysis, real electricity prices rose only for a few years in the early 1980s, and then fell continuously (at the national level) until the last year or so (2004).

Metcalf reported short-term and long-term price elasticity for electricity by four census regions. Reiss and White reported an overall average price elasticity of -0.39 for all households, elasticities by household category that ranged from -0.20 (for customers with no electric space heating or air conditioning) to -0.64 (for households with air conditioning) and -1.02 (for households with electric space heating). The authors note that these values are substantially higher than many other studies, but that they are derived from individual customer data rather than aggregate data, and they reflect careful development of marginal prices given the increasing-block tariffs in California. They also reported on the *distribution* of individual customer elasticities, finding that "44% of California households exhibit no short-run demand sensitivity to changes in the marginal price of electricity", and that the remainder of households demonstrated a skewed distribution centered at about -0.30, but with a long "tail," suggesting that roughly 1 in 8 households is price *elastic* (has a price elasticity in excess of 1 in absolute value).

Hughes, et al (2008) estimated log-linear demand equations using monthly data on gasoline consumption and prices for 1975 through 2005. Their primary objective was to compare estimated short-run price elasticity estimates for two time periods of comparably rapidly increasing prices – 1975 to 1980, and 2001 to 2006. Their basic finding was that the estimated price elasticity for the most recent period (-0.034 to -0.077) differed substantially from and was substantially smaller than the elasticity for the earlier period (-0.21 to -0.34).[12]

These results for gasoline demand do not have direct relevance to the case of electricity demand. However, they raise interesting questions regarding whether the price responsiveness of demand for electricity may have also changed from that experienced during the period of the 1980s in which many of the price elasticity studies that are usually cited were conducted.

[12] The ranges reflect results for alternative models designed to explore potential reasons for the different estimates. In addition, it should be noted that the even greater gasoline price increases that have occurred in the 2007 – 2008 time period (until the recent sharp drop), along with the slowing economy, appear to have begun reducing gasoline demand substantially, such that if this period were included in the analysis the resulting elasticity might differ from those reported in the paper.

B
DATA AND ANALYSIS APPROACH

The regressions estimated for this study are based on the following data, which are all reported from government sources at the state level (except for the GDP deflator):

- Annual electricity sales, revenues, and number of customers from the Energy Information Administration (EIA);
- Annual natural gas sales and revenues from the EIA;
- Annual CDDs and HDDs from the National Climatic Data Center (NCDC);
- Per capita disposable personal income from the Bureau of Economic Analysis (BEA);
- GDP deflator from the BEA (national level only); and
- Annual population from the BEA.

The data listed above are jointly available for the 1993 to 2007 time period for electricity and 1993 to 2006 for natural gas. All of this information has been used in the regression models. Models were estimated for both *Total electricity sales* and *Residential sales*.

Each model was estimated as a panel model with fixed state effects[13], using the following functional forms:

For electricity (*t* indexes years, *s* indexes states):

$$\ln(UPC)_t = \Sigma_s a_s + b_{lag} \bullet \ln(UPC)_{t-1} + b_{pr} \bullet \ln(avg\_rev)_t + b_{inc} \bullet \ln(pcdpi)_t + b_{gas} \bullet \ln(p\_nat\_gas)_t + b_{CDD} \bullet CDD_t + b_{HDD} \bullet HDD_t + b_{trend} \bullet Year_t + e_t$$

UPC (use per customer) is electricity sales divided by the number of customers

a_s are the state fixed effects

avg_rev is real electricity revenues divided by sales

pcdpi is real per capita disposable income

[13] A panel model is estimated using cross-section data (*i.e.*, observations for each state) for which data are also available for a time series of several years. In estimation, the error term of the regression is allowed to vary by state. Alaska and Hawaii are excluded due to data availability issues, but the District of Columbia is included.

p_nat_gas is the real natural gas total average price (labeled the "NNTCD" series by EIA)

CDD is cooling degree days

HDD is heating degree days

Year is the current year, serving as a time trend variable

For natural gas:

$$\ln(Sales)_t = \Sigma_s a_s + b_{lag} \bullet \ln(Sales)_{t-1} + b_{pr} \bullet \ln(p\_nat\_gas)_t + b_{inc} \bullet \ln(pcdpi)_t + b_{elec} \bullet \ln(elec\_avg\_rev)_t + b_{CDD} \bullet CDD_t + b_{HDD} \bullet HDD_t + b_{trend} \bullet Year_t + b_{pop} \bullet \ln(Population)_t + e_t$$

Sales is natural gas sales[14]

a_s are the state fixed effects

p_nat_gas is the real natural gas total average price (labeled the NNTCD series by EIA)

pcdpi is real per capita disposable income

elec_avg_rev is real electricity revenues divided by sales

CDD is cooling degree days

HDD is heating degree days

Year is the current year, serving as a time trend variable

Population is the state's annual population

The functional form of these equations is based on the Houthakker et al (1974) flow-adjustment model (which was also used in the 2005 RAND study).[15] Short-run price elasticity values are represented by the coefficient on the logarithm of the price variable, b_{pr}. Long-run price elasticity are obtained by adjusting the short-run elasticity by a term involving the coefficient on the lagged usage variable $-b_{pr} / (1 - b_{lag})$. Short-run elasticities are generally considered to refer to a time frame of less than three to five years, during which consumers do not have time to make investments in new capital stock. Long-term elasticities generally refer to time frames of greater than five years, in which changes in capital stock as well as changes in utilization of existing stock may be made.

[14] The number of customers is not available for natural gas, which prevents the estimation of use per customer.
[15] Houthakker, H .S., Philip K. Verleger, Jr., and Dennis P. Sheehan, "Dynamic Demand Analyses for Gasoline and Residential Electricity," *American Journal of Agricultural Economics*, Vol. 56, No. 2, May 1974, pp. 412–418.

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
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