Counterfactual analysis of energy efficiency policies in the U.S. across three decades: A time series cross section approach

Marvin J. Horowitz, Ph.D.
President, *Demand Research*
USA
mhorowitz@cox.net

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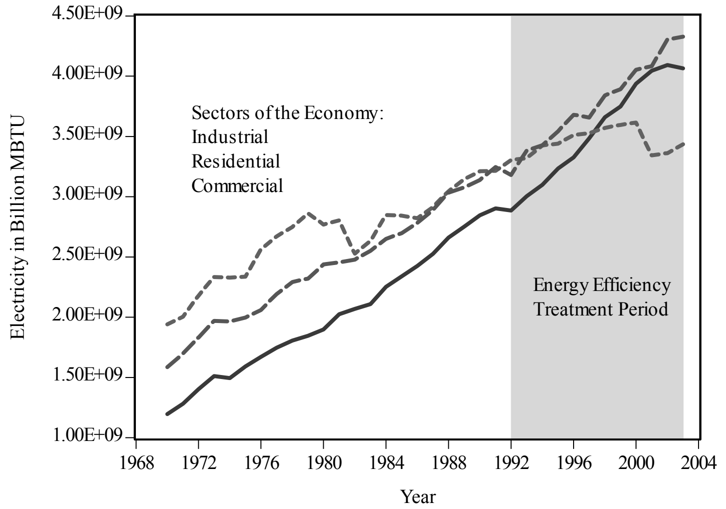
Abstract
This paper describes a statistical methodology that measures the net annual impacts of energy efficiency policies at the aggregate level. This methodology joins together the econometric techniques of time series cross section modelling and counterfactual analysis, creating a program or policy evaluation approach that is parsimonious, transparent, robust and generalizable. Among its many advantages, it can be adapted to any pre-defined multi-regional area, such as the United States or the European Union, or sub-regions, using readily available published data from government or public agencies. The findings presented in this paper indicate that in the United States, strong policy commitment at the state level resulted in substantially positive energy efficiency policy impacts in the commercial and industrial sectors. The findings for the residential sector are mixed, possibly due to complications that arise from spillover and earlier policy adoption in this sector of the economy.

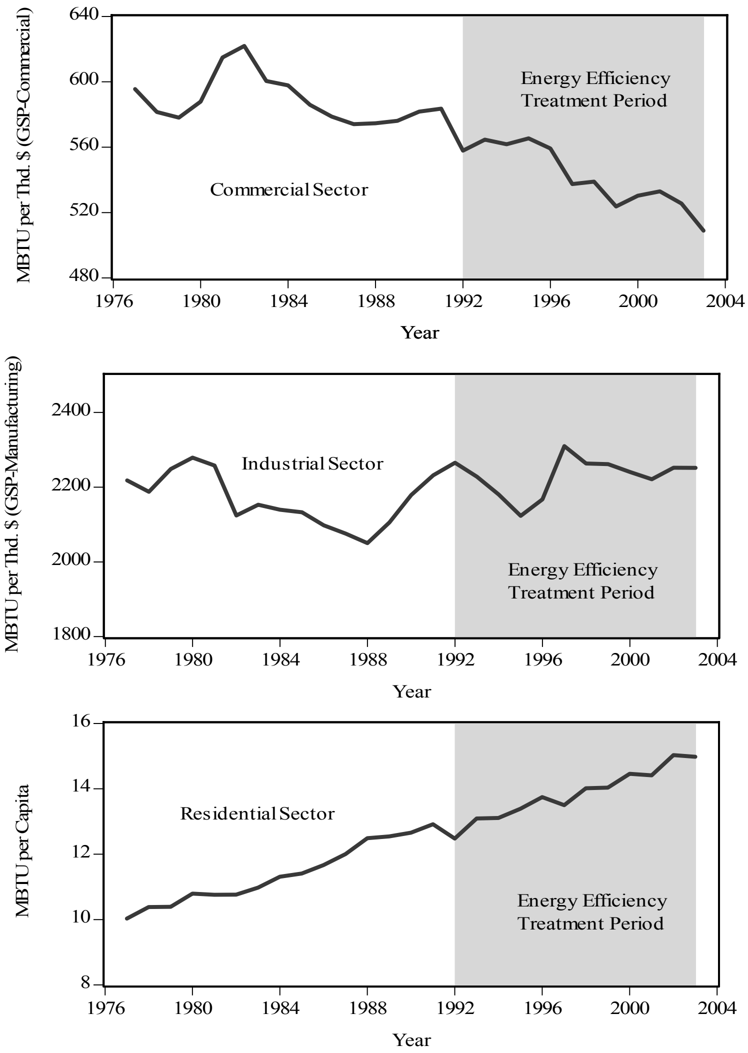
Introduction
Before the impacts of energy efficiency programs and policies can be estimated (in this paper policies will be used to refer to all publically-funded, administered, or regulated efforts, irrespective of mode or organizational origin) accurate measurements and understanding of the base condition is essential. In the energy industry, not only is estimation of energy savings controversial, but because there are many different ways to characterize energy use, gaining an appreciation for the base condition is itself controversial. This complicates the efforts to measure policy impacts because energy savings is not directly observable and thus different characterizations of base conditions can imply different types of changes in energy use and different energy efficiency policy impacts.

Graph 1, for example, displays trends in electricity consumption, aka retail electricity sales, by the three major sectors of the U.S. economy (the fourth major sector, transportation, consumes but a small amount of electricity). These data are produced state-by-state from the Energy Information Administration based on a census of actual sales from electric utilities and other retailers. As can be seen, the area of the graph from 1992 and beyond is shaded and labeled as the energy efficiency treatment period. This distinction permits comparison between two sets of years. In the pre-1992 years, referred to as the base period, many of the 48 states either had no energy efficiency policies at all, or were only just beginning to experiment with policies. However, by 1992 a small number of states had aggressive or mature energy efficiency policies and a larger number had new and growing policies. Of course, there remain, to this day, a number of states that continue to have little or no involvement with energy efficiency policies.

Although the cutoff between periods is obviously inaccurate for individual states and perhaps even for different sectors (for example, it is well-established that California, Wisconsin, and Massachusetts, had strong program commitments well prior to 1992 and that the earliest policies were residential), this cutoff year is a useful starting point. This is because it was the first year in which a major new national energy policy, the Energy Policy Act of 1992, took effect. For another, it was the first year



Graph 1. Retail Electricity Sales, 48 States, 1970 to 2003



Graph 2. Electricity Intensity by Sector, 1977 to 2003

in which large scale national programs like the Environmental Protection Agency's Green Lights and ENERGY STAR became operational.

The visual evidence shows that despite policy efforts, for all three sectors of the economy electricity use maintained an upward trajectory since 1970s. Only around 1999 or 2000 do these trends appear to taper, and only time will tell whether or not these changes in trajectory are temporary or permanent. It is with such prima facie evidence that many economists and policymakers conclude that energy efficiency policies have had little or no impact on energy use.

Another way of looking at these trends a different perspective on energy use and consequently on energy efficiency policies. In Graph 2, three panels are presented, each containing sectoral electricity intensity trends. At the top, service sector, or as known in the U.S. *commercial* sector, electricity intensity is characterized by MBTU of electricity use per dollar of the commercial sector component of gross state product (GSP) for the 48 states. Likewise, in the industrial sector electricity intensity is characterized by MBTU of electricity use per dollar of the manufacturing sector component GSP. All dollar values in these graphs, and in the remainder of this study, are standardized to the year 2000 using the gross domestic product (GDP) implicit price deflator. In the lower panel, residential sector electricity intensity is constructed as residential sector electricity use per capita.

These trends paint a somewhat different picture than the former ones. Here, commercial sector energy use relative to commercial sector economic activity appears to be declining more steeply in the treatment period compared to the base period; industrial sector relative use appears to be volatile but somewhat constant, and residential sector relative use seems to maintain the same trend in the treatment period as it had in the base period. This evidence is more ambiguous than the evidence in Graph 1, suggesting that at the very least, substantial energy efficiency policy impacts should not be dismissed out of hand.

Staffs of public agencies and research institutions in California exhibit similar graphs of residential electricity intensity as evidence that California's aggressive energy efficiency policy portfolio achieved the intended effect of damping consumer electricity demand in California. The trend for the residential sector, found in the lower panel of Graph 3, clearly shows that from 1970 to 2003 residential per capita use in California grew at a much slower rate than that of the other contiguous 47 states (when combined into a single entity that excludes California, Hawaii, and Alaska, this union is referred to as US47). This is particularly true after 1976, about the time California launched its first residential energy efficiency programs -- these were among the first energy efficiency policies in the nation; many years later wide-ranging commercial and industrial sector policies were adopted in California and elsewhere.

To complete the picture painted by the residential graph, the two upper panels of Graph 3 contain similar comparisons for the commercial and industrial sectors. As can be seen, the commercial and industrial sector trends in California appear to be more favorable than the US47 trends. In both sectors, electricity intensity appears to be declining at a faster pace in California than in US47. While the differential trends may not be as pronounced as in the residential sector, they seem to suggest that strong energy efficiency program commitments have substantial impacts on electricity intensity in these sectors, too.

The point of these illustrations is to show that how energy use is characterized, and what it is compared to, can make a dramatic difference in how changes in energy use and energy efficiency policy impacts are not only measured, but perceived. This has consequences for the economy and the environment, both locally and globally, because these perceptions influence both private decision making and public policy making.

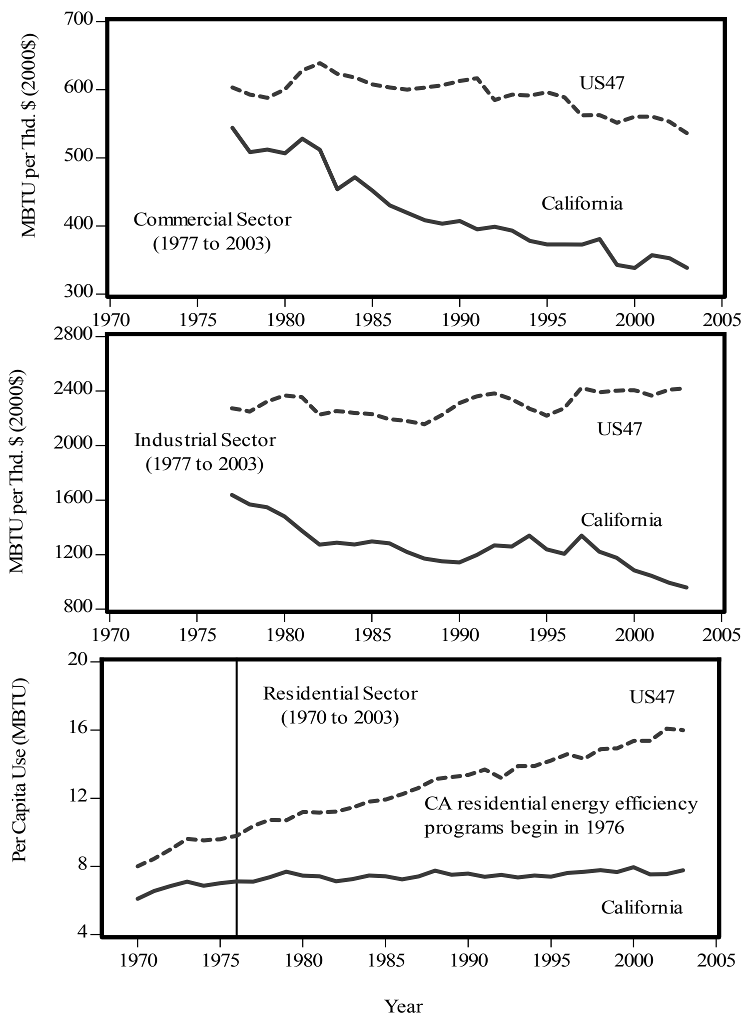
Counterfactual Analysis

Calculating various ratios and their trends over time, also known as energy indicators, is a starting point for assessing changes in energy use but generally provides only a limited amount of information. For example, the ratio of annual BTU to annual GDP controls for only one time-related dimension. It does not allow for; (a) a simultaneous adjustment of BTU for other dimensions, such as energy prices and weather, that affect BTU differentially over time; (b) an estimate of how a percentage change in GDP relates to a percentage change in BTU (known as the elasticity of BTU with respect to GDP); or (c) a cross-governmental comparison of BTU where the different governments have noticeably differing economic, demographic, political or geographic characteristics.

To permit some degree of cross-governmental comparability, energy intensity ratios can be normalized by a sequential application of weights for different independent variables. This is the approach adopted by the International Energy Agency and ODYSSEE (see for example, Didier Bosseboeuf, Bruno Lapillonne, and Wolfgang Eichhammer, "Measuring Energy Efficiency Progress in the EU: The Energy Efficiency Index ODEX," Proceedings of the 2005 ECEEE Summer Study, pp. 1127-1135). For example, differences in weather among EU countries are controlled for by national weights. Likewise other weights are applied to adjust for industrial mix, purchasing power parity, and so on, as appropriate for different indicators.

This kind of normalization process improves the comparability of the ratios but imposes strong statistical restrictions on the outcome. For one, it assumes that every weight is independent of every other weight, in other words, that the adjustment variables do not covary. For another, it assumes that the impact of a change in the adjustment variable on energy use is constant across governments and across different policy regimes. Moreover, as noted above, the amount of behavioral information that can be used for policymaking is limited in that conventional elasticities, and for that matter conventional confidence intervals and statistical testing, cannot be calculated.

The present study offers an alternative to the European approach. Following recent studies (for example, Marvin J. Horowitz, "Electricity Intensity in the Commercial Sector: Market and Public Program Effects." The Energy Journal, Vol. 25, No. 2, pp. 115-137, Spring 2004), to fully address the complexity of calculating energy intensity indicators and hence energy efficiency, time series cross section reduced-form demand equations are specified and estimation. Coupled to these models, this study offers an innovation in energy efficiency program and policy evaluation, namely, an innovative counterfactual analysis. As will be shown below, this approach is based on well-accepted



Graph 3. Comparison of California with US47

econometric principles, is parsimonious, transparent, robust, reproducible, and capable of standardization and periodic updating. These features, and the fact that the kinds of annual time series data that are used in these analyses are publically available data from government or public agencies, recommend this approach as a general, low-cost methodology that can be adapted to collections of nations, regions, sub-regions, and jurisdictions.

In this study, an electricity intensity model is specified using a uniform set of variables and a common functional form for all three sector. These constraints are not imposed out of necessity, but rather for practicality. The independent variables for each sector are, respectively, the average retail price of electricity (P); the average retail price of natural gas (N); state economic status as captured by per capita income or GSP (G); climatic conditions, i.e., heating (H) and cooling (C) degree days; and lastly, a time trend related to technological change in each sector (T). Technology trend data are from the Federal Reserve Board and are sector-specific. For the residential sector, market group index B51121 is employed; it represents U.S. production of a subset of electronic equipment, namely, computers, video, and audio equipment. For the commercial sector, market group index B52120 is employed; it represents the production of products that are more closely associated with the business world such as information processing and related equipment. Finally, for the industrial sector, market group index G334 is employed. It represents computers and related equipment, and is the broadest category among the three trends. The general function is:

$$EI_{t,s,R} = f(P_{t,s,R}, N_{t,s,R}, G_{t,s,R}, H_{t,s,R}, C_{t,s,R}, T_{t,R})$$

in which subscript t represents a given year; subscript s represents a given state; and, subscript R represents a discrete level of commitment to energy efficiency policies.

This split-case function asserts that R influences each of the behavioral relationships associated with electricity intensity. In other words, R is a transformative agent. To identify R, a variety of secondary quantitative and qualitative sources were consulted. This results in a ranking of the 48 states into quartiles – one strong (S) , two moderate (M), and one weak (W) – based on a general indicator of state support and encouragement of energy efficiency, referred to as policy commitment (the details of the development of this ranking scheme are contained in a forthcoming study referenced in the concluding section of this paper). With the division of years into base and a treatment periods, and the division of states into policy commitment quartiles, policy contrast is available via four grouping of observations; (1) states with strong or moderate commitment in the base period; (2) states with strong or moderate commitment in the treatment period; and, (3) and (4) states with weak commitment in both periods.

Estimating the impact of key factors on energy intensity, and in particular the impact of program commitment on energy intensity, requires a behavioral model of electricity intensity through which a simulation can be performed. This simulation estimates what might have occurred to one group of observations had they experienced the conditions of the other group of observations. Because the condition in question is policy commitment, and because contrasting commitment across states is nearly impossible to identify with precision, the most viable groups of observations that can be used for estimating the electricity intensity model will those on the opposing ends of policy commitment. Hence, a model is estimated based on the specification

$$EI^{W} = \beta_0^{W} + \sum_{j=1}^{n} \beta_j^{W} X_j^{W} + u^{W}$$

where the superscript *W* represents states that fall into one or the weak program commitment quartile. In this specification, time series and state subscripts are suppressed, the β_j's are the coefficients associated with each of the X_j independent variables, and the *u*'s are independent error terms. For any collection of years over which this models are estimated, the counterfactual is estimated by inserting the mean *X*'s from one group into the other group's model. For example, using the *W* quartile's model, the values for the combined quartiles of strong and moderate commitment states, *SM* , can be used for calculating the counterfactual such that

$$EI_{Counterfactual}^{SM} = \beta_0^{W} + \sum_{j=1}^{n} \beta_j^{W} X_j^{SM}$$

In this way, the electricity intensity model is used to simulate the mean electricity intensity of *SM* states had their demand behavior been like that of the *W* states.

Table 1 contains the estimated models for all three sectors for the *W* states for the base and treatment period. However, it must be noted that the base period for the residential sector was shifted from the years 1997 through 1991 to the ten years of 1970 through 1979. This period is referred to as the *Base70* period and is motivated by the initial findings showing that in the original base period there was little behavioral difference between the strong and weak commitment states. This could imply that strong commitment had no effect, or a perverse effect, on energy consumption. However, it could also imply that the model coefficients are biased because of an inappropriate base period and/or spillover from strong and moderate commitment states to the *W* states in the base period. The latter seem the more likely explanations, since it is well known that residential policies began in earnest in the early 1980s, well before commercial and industrial policies, and that the residential sector is generally more responsive to mass marketing and consumer outreach than the other sectors.

For each model, the reported R-squared is derived from a deviation-from-means specification, all of the variables are in natural log form, and a GLS fixed effects, weighted least squares estimator is employed. This estimator minimizes heteroscedasticity by allowing for different residual variances for each cross section; in addition, the fixed effects accounts for unobserved, state-specific factors, such as location-specific conditions and self-selection, that permanently affect state electricity use. Diagnostics indicate that the estimated equations need not be corrected for unit roots or autocorrelation, and all the standard errors are White-corrected. Based on these models, Table 2 contains the impact estimates of program commitment, in levels of electricity consumption, or GWh, as well as in electricity intensity, for the *SM* states.

For each sector, the first row contains the factual, annual mean GWh use and electricity intensity for the *SM* states for the base period and the treatment period, and the percentage change from the base period.

The second row provides the same information for the counterfactuals, and the third row contains an approximation of the 95 percent confidence levels of the counterfactuals based on the average standard errors, or relative standard errors in the case of electricity intensity, of the individual observations. Finally, the fourth row contains the difference of the changes, in percent. This statistic, labeled *net impact*, is the difference between what the percentage change in consumption for the *SM* quartiles actually was, and what the simulation said it would have been had these states behaved like the states in the *W* quartile. By this study's definition, the net impact is the aggregate effect of state energy efficiency policy commitment on electricity demand.

Both the energy intensity and energy consumption findings in the commercial and industrial sectors are consistent with the expected impacts of energy efficiency policy commitment. Moreover, their estimates of energy intensity and energy consumption impacts do not widely differ. Net impacts reveal that

Table 1: Electricity Intensity Models, W States

Sector	Commercial		Industrial		Residential	
Variables/Period	Base	Trt.	Base	Trt	Base70	Trt.
constant	4.108	6.622	9.498	4.062	-2.347	0.783
s.e.	0.708	1.318	0.863	1.418	1.004	0.440
Electricity Price	0.077	-0.219	-0.433	0.234	-0.210	-0.384
s.e.	0.074	0.110	0.058	0.136	0.041	0.046
Natural Gas Price	-0.108	0.034	0.119	0.084	0.040	0.063
s.e.	0.031	0.034	0.032	0.042	0.036	0.017
Per Capita Inc/GSP	-0.545	-0.361	0.033	-0.743	0.510	0.150
s.e.	0.076	0.170	0.083	0.271	0.147	0.075
Technology Trend	0.170	0.018	-0.131	0.186	0.213	0.015
s.e.	0.013	0.037	0.015	0.034	0.060	0.008
Heating Degree Days	-0.037	-0.062	-0.059	-0.006	0.391	0.217
s.e.	0.054	0.096	0.074	0.090	0.093	0.032
Cooling Degree Days	0.016	-0.043	0.074	-0.028	0.036	0.086
s.e.	0.040	0.048	0.048	0.062	0.038	0.018
D.V. Mean	6.462	6.426	7.976	8.040	2.281	2.705
n	180	144	180	144	120	144
adj. R2	0.54	0.39	0.72	0.69	0.99	0.92

Table 2: Net Impacts of Energy Efficiency Policy Commitment

	Level of Electricity (GWh) Use			Electricity Intensity		
Statistic	Base	Treatment	% Change	Base	Treatment	% Change
	Commerical					
Factual	558,303	865,047	54.9%	627.4	578.7	-7.8%
Counterfactual	664,761	1,111,229	67.2%	689.6	692.2	0.4%
95% C.L. (+/-)	22.4%	34.5%		3.4%	5.2%	
Net Impact			-12.2%			-8.1%
	Industrial					
Factual	675,353	793,024	17.4%	2,928	2,898	-1.0%
Counterfactual	925,015	1,175,135	27.0%	2,787	3,088	10.8%
95% C.L. (+/-)	21.9%	31.0%		2.9%	4.1%	
Net Impact			-9.6%			-11.8%
	Residential (Base 70)					
Factual	496,863	949,968	91.2%	9.9	14.5	45.9%
Counterfactual	486,993	919,711	88.9%	9.3	13.9	50.3%
95% C.L. (+/-)	18.3%	8.2%		8.9%	3.1%	
Net Impact			2.3%			-4.4%

even though energy use grew for the *SM* states, even greater growth would have occurred had their policy commitment been weaker. In the commercial sector, the net impact of commitment was a reduction in use of 12.2 percent in electricity use from the base to the treatment period, and a reduction of 8.1 percent in energy intensity. In the industrial sector, the net impact was a reduction of 9.6 percent in electricity use, and a reduction of 8.1 percent in energy intensity relative to what it might otherwise have been with weaker commitment. The findings for the residential sector are mixed. They show that residential energy consumption increased 2.3 percent in the *SM* states relative to what it would otherwise have been. However, energy intensity for these states shows a decline of 4.4 percent.

While there is little reason to suspect that structural differences are present in the residential and commercial sectors between the *SM* and *W* states, it is reasonable to question whether or not structural differences could be affecting the industrial sector findings. As such, the subject of differential industrial mix has been investigated. It points to the overall mix of industries being comparable across quartiles and thus lends credence to the validity of the industrial sector counterfactuals. According to the EIA's 2002 Manufacturing Energy Survey (MECS) the top ten electricity-consuming industries nationally, of which the largest electricity users are chemicals, primary metals, and paper, accounted for the overwhelming majority of industrial sector electricity use in 2002, a total of 82.9 percent. In 1977, these ten industries accounted for 57 percent of manufacturing GSP in the *W* quartile, and 62 percent of manufacturing GSP in the *SM* quartiles; moreover, the proportions remain much the same through the years, such that by 2002 they account for 61 percent of manufacturing GSP for the *W* quartile and 66 percent for the *SM* quartiles. These general facts suggest that structural differences do not bias the net impact findings in the industrial sector

Conclusion

This paper presents rigorous empirical findings of broad changes in electricity demand in the United States over a three decade period. The evidence suggests that, on average, those states that have moderate to strong commitment to energy efficiency policies reduce energy intensity in their states relative to what it would have been with weaker commitment. In addition, these findings hold for changes in the levels of energy consumption in the commercial and industrial sectors, if not the residential sector. Moreover, due to the inherent imprecision in the state policy commitment rankings and cutoff periods, these findings are likely to understate net impacts. These substantive results have important implications for how energy policymakers should view energy efficiency policies.

The findings of the counterfactual analysis raise several issues that are investigated further using this evaluation methodology. Chief among these issues is the extent to which the net impacts are determined by differences in average state characteristics or differences in electricity demand behavior. Also, since behavioral responses to the independent variables may be conditioned by policy commitment, the relative importance of each variable's coefficient to the difference in the means of the dependent variables in each period is measured and compared. These analyses permitted exploration into the phenomenon of demand transformation and spillover, topics of particular interest to policymakers who, since the mid-1990s, have sought to develop policies that have long-lasting, or transformative, effects on the markets for energy and energy-related equipment. A more comprehensive version of this paper in which there is a detailed description of these analyses, as well as a more detailed discussion of the data and research design, is contained in a forthcoming study in *The Energy Journal*, Vol. 28, No. 3, July 2007, entitled "Changes in Electricity Demand in the United States from the 1970s to 2003."