A comparison of national energy efficiency policy evaluation methods: models versus indexes

Marvin J. Horowitz, Ph.D.
President, Demand Research LLC
USA
mhorowitz@demandresearch.net

Keywords

policy evaluation, econometric models, energy efficiency index, energy demand, IPMVP methods

Abstract

Energy efficiency and sustainable environmental policies are expanding in scope and purpose throughout the world. To ensure the success of these initiatives in meeting their goals, and to monitor the effects of policies from year to year and from country to country, there is a growing need for improved policy monitoring and evaluation research. Towards this end, this paper focuses on understanding the advantages and disadvantages of two distinct statistical approaches to evaluating the annual impacts of national energy efficiency policies. One of these is an econometric modeling approach in which times series, or cross section time series, regression models are used to compare actual energy use to counterfactual (business-as-usual or baseline) energy use, while the other is an index approach in which the energy efficiency portion of a multi-sector energy intensity index is isolated. Using empirical data on energy consumption within the United States, specific comparisons are made between the two approaches to show how each are constructed. This paper should help guide future energy efficiency evaluation planning efforts, such as the EMEEES project, in determining which approaches should be applied to policy analysis.

Introduction

Energy efficiency and sustainable environmental policies are expanding in scope and purpose throughout the world. To ensure the success of these initiatives in meeting their goals, and to monitor the effects of policies from year to year and from country to country, there is a growing need for improved policy monitoring and evaluation research. In the United States, where utility service territory and state and local energy efficiency programs have proliferated since the mid-1970s, there is widespread experience with monitoring, verification, and evaluation of energy efficiency measures, projects, and programs.

The details of many of these studies are be found in the official proceedings of national conferences such as those sponsored by the American Council for an Energy Efficient Economy and the International Energy Program Evaluation Conference. Furthermore, at least ten publications in the past two decades, the most prominent of these being the "International Performance Measurement and Verification Protocol" (IPMVP, 2002 and 2007), provide instructions for doing quasi-experimental program evaluations using microdata. Indeed, even the European Commission's project on evaluation and monitoring for the end-use directive on energy end use and energy services (EMEEES, 2008) proposes to use the four basic IPMVP approaches to guide energy efficiency evaluations in the twenty-seven European Union countries. This broad acceptance, along with the thousands of completed program evaluations that more or less follow the IPMVP approaches, leaves the powerful impression these techniques produce savings estimates that are adequate, when added up, for measuring large scale policy-related savings.

Alas, this impression is most-likely false. While it is not within the scope of this paper to elaborate on the reasons why the IPMVP techniques are not sufficient for measuring the long-term energy savings of energy efficiency policies (another paper currently in the works will perhaps be the first of its kind to tackle this task), several salient negatives attributes of the IPMVP methods are worth noting:

- an emphasis on verification of some savings-related variables but not others;
- an emphasis on estimating average rather than total savings means that cross section sampling, and its attendant biases, is unavoidable;
- an emphasis on short-term savings, thereby assuming that savings is static and and obstructing investigation of how social, technological, and economic trends play out over time;
- an emphasis on mischaracterizing program savings due to invalid estimation of free ridership and spillover;
- an underestimation of uncertainty due to incomplete information on the standard error or savings.

In fact, few evaluations have ever measured aggregate or policy-related energy savings on a large scale, be it at the utility, state, or national level. In this paper, *energy efficiency policy* is a term meant to describe the sum of all public or regulatory-sponsored measures, projects, and programs implemented in a defined geographic territory for a particular fuel in a particular economic sector. They include free educational, audit, and public-private partnership programs; building codes and appliance standards; financial incentives or tax subsidies for purchasing products or undertaking individual projects; utility-sponsored promotions, and so on. Individual programs, projects, and measures are hardly ever expected to produce detectable changes in aggregate energy use trends. Collectively, however, they are hardly ever expected *not* to produce such changes.

Without much in the way of experience with measuring the savings from energy efficiency policies, a method that has attracted a good deal of international interest is the energy efficiency index. Energy intensity, energy indicators, and energy indexes of all kinds have been studied and examined for many years. Engineers and energy professionals employ them to measure manufacturing and services productivity, economists employ them for analyzing energy inputs, outputs, and the components of demand, and policymakers employ them to digest, summarize, and communicate trends about the economy. In many contexts, these statistics have important and valid uses. Indeed, their uses in a broad range of applications is unquestionable.

The purpose of this paper is to compare the conceptual underpinnings, and empirical findings, of the two non-IPMVP approaches to measuring large scale policy-related savings. The first of these, referred to above, is the energy efficiency index approach. The other is an econometric modeling approach for studying changes in national electricity demand that was first developed in Horowitz (2007) where it was applied to estimate the impacts of electricity energy efficiency policies in the commercial, industrial, and residential sectors from 1992 to 2003. A more in-depth comparison of these approaches using a Monte Carlo simulation to estimate the probability and closeness of agreement of these two methods' findings in contained in Horowitz (2008).

The energy efficiency index

In the academic literature an energy efficiency index is identified as a component-based, as opposed to an aggregate index, the most well-known among the latter being the simple energy intensity ratio defined as total national energy consumption divided by gross domestic product, or E/GDP. Much of the attractiveness of a component-based index approach to policy evaluation stems from its minimal data requirements, simplicity of computation, and ease of analysis, comparison, and communication. Also, a single standardized method that all countries or jurisdictions can agree on can eliminate controversy and delay in evaluating energy and environmental policies. In other words, there are many practical reasons for adopting this approach.

To illustrate how the component-based index approach leads to an energy efficiency index, Table 1 provides actual data for the 48 contiguous states of the U.S. for electricity consumption in 1991 and 2006 for the residential, commercial, and industrial sectors, in MBTU. Using these data, a well-known index formula is used for calculating the energy efficiency index (ODYSSEE, 2007). In the three-sector case,

$$
\begin{aligned}
&\text{Energy Efficiency Index} = \\
&\left[\left(\frac{E_1}{P_1}\bigg/\frac{E_0}{P_0}\right)\times\left(\frac{E_1}{E_1+F_1+G_1}\right)\right]+\left[\left(\frac{F_1}{Q_1}\bigg/\frac{F_0}{Q_0}\right)\times\left(\frac{F_1}{E_1+F_1+G_1}\right)\right] \\
&+\left[\left(\frac{G_1}{R_1}\bigg/\frac{G_0}{R_0}\right)\times\left(\frac{G_1}{E_1+F_1+G_1}\right)\right]
\end{aligned}
$$

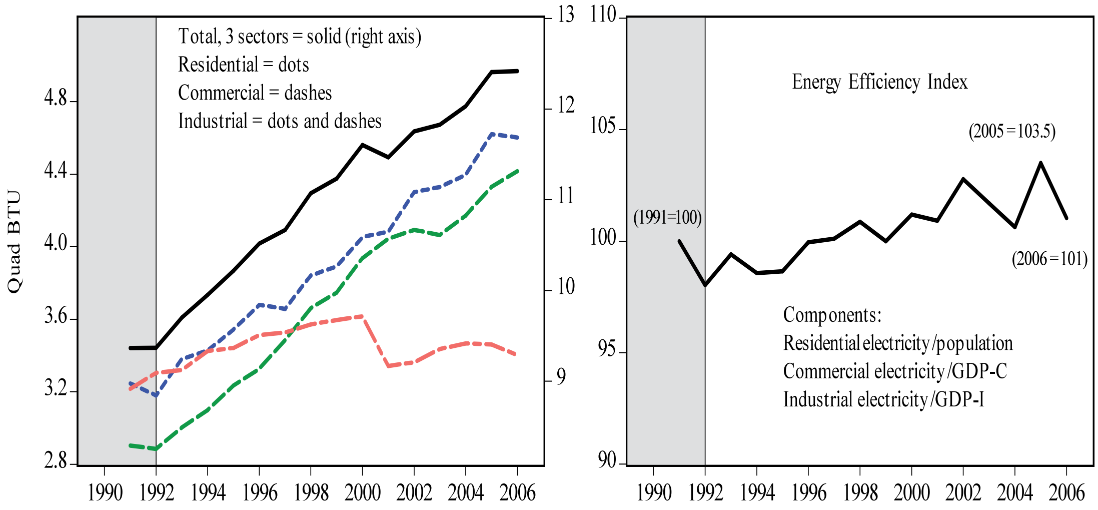
where subtracting 1 from the energy efficiency index allows the index to be interpreted as the percentage change in energy efficiency from the base year. In this example:

E = commercial sector electricity consumption
P = real GDP for the commercial sector
F = industrial sector electricity consumption
Q = real GDP for the industrial sector
G = residential sector electricity consumption
R = U.S. population
time 0 = base year 1991
time 1 = a single specified year.

Graph 1.A shows the electricity consumption trends for the three major sectors of the U.S. economy separately, and combined, for the 48 U.S. states. In all, the combined consumption of these three sectors represents more than 95 percent of total annual U.S. electricity consumption and, as can be seen, has increased by about 40 percent from 1991 to 2006. This information can be aggregated, as in Graph 1.B, by an energy efficiency index, revealing that in some sense the rise in energy use is not as dramatic as it seems. For this index, the electricity consumption of each of the three sectors is transformed into an energy intensity ratio, and then these ratios are combined into a single index. By subtraction, according to the energy efficiency index, U.S. energy efficiency in 2006 decreased, or worsened, by 1 percent relative to the the base year of 1991. Note that in 2005 energy efficiency worsened by 3.5 percent relative to 1991; to

Table 1: U.S. Electricity Consumption Energy Efficiency Index

		Unit	1991	2006
Consumption	**Variable**		**Actual**	**Actual**
Commercial	E	ESCBMBTU	2,902,594,618	4,416,874,944
Industrial	F	ESIBMBTU	3,215,279,349	3,401,105,484
Residential	G	ESRBMBTU	3,246,241,328	4,602,559,396
Units				
Commercial	P	REALGCP	4,973,703	8,864,381
Industrial	Q	REALGMP	1,440,702	1,587,345
Residential	R	POP	251,273,994	297,448,000
Unit Consumption				
Commercial		MBTU/REALGCP	583.6	498.3
Industrial		MBTU/REALGMP	2231.7	2142.6
Residential		MBTU/POP	12.9	15.5
Unit Consumption Index				
Commercial		1	100.0	85.4
Industrial		1	100.0	96.0
Residential		1	100.0	119.8
Consumption Share				
Commercial		1	0.310	0.356
Industrial		1	0.343	0.274
Residential		1	0.347	0.371
Efficiency Index				
Index (1991=100)				**101.03**



Graph 1.A and 1.B: U.S. Electricity Use and Energy Efficiency Index (3 Sectors)

smooth these annual fluctuations, moving averages of the index are often the preferred way to report results.

Econometric modelling of energy demand

The simplest econometric modeling approach uses a time series model for a single subject, such as a country or a state or a utility, to compare its actual energy demand to that which would have been demanded in it's absence. There are two features of this approach that determine its success. The first is historical knowledge. Knowledge of a subject's energy efficiency programs and policies is necessary for selecting a date, or dates, when policy changes are likely to have occurred or when their effects are likely to be detectable. In addition, background knowledge of other major events, or social and economic changes, that may have also affected demand over the study period is critical for developing and testing hypotheses and for interpreting findings. The second ingredient for success is knowing enough about a subject to be able to specify a reasonable econometric model of aggregate energy demand. Given these prerequisites, a general function for a time series energy demand model, where the subscript t represents a given year and the subscript R represents policy regime change related to energy efficiency, is:

$$Y_{t,R} = f(P_{t,R}, N_{t,R}, G_{t,R}, W_{t,R}, T_{t,R}).$$

In this function Y could be an absolute or relative quantity of energy demand, and policy regime change R is assumed to influence the behavioral relationships associated with Y. Determinants of energy demand may include and are not limited to electricity prices as represented by (P); natural gas prices as represented by (N); absolute or relative incomes as represented by (G); climatic conditions as represented by (W); and time trends as represented by (T). Estimating a model based on this function for the years prior to regime change, Y can be projected or simulated in the post-regime change years. This provides the necessary counterfactual by which the impacts of the policies, i.e. energy savings, can be empirically measured.

An extension of the time series model involves using cross sectional data, meaning groups of subjects, be they nations, states, utilities, etc., to estimate the impacts of energy efficiency policies. This version is more complicated than the former because it hinges not only on accurate dating of policy and non-policy regime changes and on appropriate model specifications, but also on creating groupings of subjects that have similar energy efficiency policies. On the other hand, it can be applied much more broadly and can yield much more information than a single subject time series analysis. When multiple subjects with time series data are analyzed, the models are referred to as pooled cross section time series, or panel, data. The function now appears as:

$$Y_{t,s,R} = f(P_{t,s,R}, N_{t,s,R}, G_{t,s,R}, W_{t,s,R}, T_{t,R})$$

where policy regime change now is assumed to occur for some cross sections and years and not others, and to be similar in quality, scope, and timing. Fundamentally, like the simpler version for a single subject, this approach relies on variations in governmental policies across years and cross sections for describing and explaining changes in trends. Rather than a hindrance, the many different degrees of commitment to energy efficiency policies found in nations, states, jurisdictions, service territories, neighborhoods, and small towns, provide excellent opportunities for measuring policy-related savings.

Numerous well-known studies use pooled time series cross section models to study energy demand, dating at least as far back as Fisher and Kaysen (1962) and including Halvorsen (1975), and Taylor et. al (1984). However, interest in this approach ebbed in the 1980's with the rise of large scale economic-engineering energy modeling on the one hand, and cross sectional quasi-experimental energy efficiency program evaluations on the other. Nevertheless, there is an enduring role for pooled cross section time series model in the energy field, as demonstrated by the recent studies of Bernstein, et. al, (2003), Loughran and Kulick (2004), Horowitz (2004), and Metcalf (2008).

Using such models and devising groupings of years and cross sections representing different policy regimes for the 48 states, Table 2 contains long-term energy efficiency policy impact for the U.S. using the exact same data and base year as was used for constructing the energy efficiency index.

The counterfactual for each sector is derived from the econometric models and represents the total energy use that would have occurred in 2006 in the absence of energy efficiency policies. As can be seen, the impacts vary by sector, with energy efficiency policy shown to have caused an unintended increase in residential use. However, overall energy efficiency policy is estimated to have led to a decline in U.S. electricity use of 9.9 percent compared to what it otherwise would have been. What accounts for the difference between this finding and the energy efficiency index finding of a one percent decline in U.S. electricity efficiency from 1991 to 2006?

Why the different estimated policy impacts?

Unlike the index calculation, in a conventional statistical analysis of policy impacts the calculation of the percentage change due to the policy involves levels, not ratios. Using the notation above, the combined impact of national energy efficiency policies across the three sectors is calculated as:

$$\text{Policy Impact (\%)} = \left(\frac{(E_1 + F_1 + G_1) - (E'_1 + F'_1 + G'_1)}{E_1 + F_1 + G_1}\right)$$

where E'_1, F'_1, and G'_1 represent estimates of the electricity consumption that *would have* occurred in each sector had there not been energy efficiency policies from the base period forward. These three values are called counterfactuals, or the business-as-usual scenarios, or simply, the hypothetical baselines. Whether derived from engineering calculations, from metering, from econometric models, from judgment, or whatever, the important point is that the counterfactuals represent the levels of energy use that would have occurred had there been no energy efficiency policies.

Obtaining energy counterfactuals in levels, not ratios, is the *sine qua non* of energy efficiency policy evaluation. When the policy goal is to reduce energy use, it is energy itself that matters, not energy per person, per house, per car, or per dollar. This can be seen most readily by setting the index calculation in time 1, in percent, next to the percentage policy impact calculation, as in the inequality:

Table 2: U.S. Electricity Energy Efficiency Policy Impacts (Base Year = 1991)

	Commercial	**Industrial**	**Residential**
Variable	ESCBMBTU	ESIBMBTU	ESRBMBTU
Actual Consum. -1991	2,902,594,618	3,215,279,349	3,246,241,328
Actual Consum.- 2006	4,416,874,944	3,401,105,484	4,602,559,396
Counterfactual - 2006	4,760,590,200	4,722,509,587	4,162,459,464
Policy-Related Savings	343,715,256	1,321,404,103	-440,099,932
U.S.- 48 States: Percent Impact in 2006		9.9%	

$$\left(\frac{(E_1+F_1+G_1)-(E'_1+F'_1+G'_1)}{E_1+F_1+G_1}\right) \neq$$

$$\left(\begin{array}{l} \left[\left(\frac{E_1}{P_1}\Big/\frac{E_0}{P_0}\right)\times\left(\frac{E_1}{E_1+F_1+G_1}\right)\right] \\ +\left[\left(\frac{F_1}{Q_1}\Big/\frac{F_0}{Q_0}\right)\times\left(\frac{F_1}{E_1+F_1+G_1}\right)\right] \\ +\left[\left(\frac{G_1}{R_1}\Big/\frac{G_0}{R_0}\right)\times\left(\frac{G_1}{E_1+F_1+G_1}\right)\right] \end{array}\right)-1$$

One of the noteworthy features of this comparison is not only that the percent policy impact calculation does not contain the denominators *P*, *Q*, and *R*, but that the percent change in the energy efficiency index does not contain the counterfactuals E'_1, F'_1, and G'_1. Rather, the equivalent versions of the counterfactuals are the actual values E_o, F_o, and G_o. In other words, the business-as-usual scenarios in the energy efficiency index calculation are actual energy use at time 0, not what energy use would have been in the absence of national energy efficiency policies at time 1.

The importance of this distinction is quite clear when the conventional policy impact calculation using the business-as-usual scenarios is placed side-by-side the calculation in which the actual base year values are employed as the business-as-usual scenarios:

$$\left(\frac{(E_1+F_1+G_1)-(E'_1+F'_1+G'_1)}{E_1+F_1+G_1}\right) \neq$$

$$\left(\frac{(E_1+F_1+G_1)-(E_0+F_0+G_0)}{E_1+F_1+G_1}\right)$$

To state the obvious, taking energy use in the base period, time 0, as the counterfactual assumes that the levels of energy use of each component would remain the same if it were not for energy efficiency policy. Unfortunately, absolute levels of energy use at time 1 are more likely to rise, not fall, despite energy efficiency policies. Unless counteracted by even faster growth in the denominators, the end result will be the appearance of a decrease in energy efficiency despite what might indeed be significant policy-related savings. No matter how else a counterfactual may be formulated with the limited data used for constructing the index, it will not be as valid as the counterfactual calculated from a well-specified and properly estimated multivariate econometric model.

Conclusion

In an age in which there is great concern over energy shortages and climate change, there seems little point in developing energy efficiency policies that are so modest in scope that they are expected to have little effect on long-term energy use trends. Feasibility and experimental programs aside, fielding dozens of energy efficiency programs whose sum total of measured savings, even if unbiased and accurate, does not have a noticeable impact on energy use, is not what advocates of national and international policies have in mind. A general target that many find reasonable is that energy efficiency should reduce national energy use by about one percent less per year than what it otherwise would have been. Hence, by 2020 energy efficiency policies should have at least a ten percent impact on energy use trends. More ambitious goals now being pushed in Europe and the United States call for a two percent per year decrease through 2020, or over a twenty percent decrease in energy use in 2020 from what it otherwise would have been.

The fundamental issue that this paper addresses is how to measure or verify the total, long-term energy savings that come from energy efficiency policies. Unlike what is produced by the energy efficiency index approach, and the IPMVP methods, this requires a method that is capable of estimating policy-related energy savings while controlling for market prices, incomes, and other factors related to autonomous changes in energy demand and energy efficiency. Thus far, it appears that only the econometric modeling approach controls for these factors, as well as for free riders, spillover, and other indirect effects. Because comprehensive, accurate, and reliable estimates of long-term savings are essential to the success of energy efficiency policies, more time, effort, and attention should be given to expanding and developing this measurement method.

References

Bernstein, Mark, K. Fonkych, S. Loeb, and D. Loughran (2003). *State-Level Changes in Energy Intensity and Their National Implications*, Rand, MR-1616-DOE, Santa Monica, CA.

EMEEES (2008). "Harmonised Methods for Evaluating Energy End-Use Efficiency and Energy Services – The European Commission's project on evaluation and monitoring for the end-use directive on energy end use and energy services, Final Conference," Brussels, BE.

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

Halvorsen, Robert (1975). "Demand for Electric Energy in the United States," *Southern Economic Journal*, Vol. 42, No. 4, pp. 610-625.

Horowitz, Marvin J. (2004). "Electricity Intensity in the Commercial Sector: Market and Public Program Effects," *The Energy Journal*, Vol. 25, No. 2, pp. 115-137.

Horowitz, Marvin J. (2007). "Changes in Electricity Demand in the United States from the 1970s to 2003," *The Energy Journal*, Vol. 28, No. 3, pp. 93-119.

Horowitz, Marvin J. (2007). The Trouble With Energy Efficiency Indexes: *La aritmetic non e opinione, Energy Efficiency*, Vol. 1, No. 3, Summer 2008, pp. 199-210.

Loughran, David S. and Jonathan Kulick (2004). "Demand Side Management and Energy Efficiency in the United States," *The Energy Journal*, Vol. 25, No. 1, pp. 19-43.

Metcalf, Gilbert (2008). "An Empirical Analysis of Energy Intensity and Its Determinants as the State Level", *The Energy Journal*, Vol.29, No. 3, pp 1 – 27.

ODYSSEE (2007). http://www.odyssee-indicators.org/Indicators/PDF/odex.pdf.

Taylor, Lester D, Blattenberger, G. R., and R. K. Rennhack (1984). "Residential Energy Demand in the United States: Introduction and Overview of Alternative Models" in *Advances in the Economics of Energy and Resources*, Vol. 5, pp. 85-105.

U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (2002 and updated in 2007). *International Performance Measurement & Verification Protocol*. Washington, DC.