Econometric models for distinguishing between market-driven and publicly-funded energy efficiency

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Abstract

Central to the problem of estimating energy program benefits is the necessity to differentiate between changes in energy use that would have occurred in the absence of public programs versus declines in energy use that would not have occurred *but for* public programs. The former changes are often referred to as naturally-occurring or market-driven effects. They occur due to a combination of one or more independent variables, such as changes in prices, incomes, weather, and technology. For a rigorous, scientifically-valid program evaluation, it is essential to first control for these variables before making statistical inferences related to public program effects.

This paper describes the economic and statistical issues surrounding quantitative studies of energy use, energy efficiency, and public programs. To illustrate the strengths and weaknesses of different impact evaluation approaches, this paper describes three new studies related to electricity use in the U. S. commercial buildings sector. Specification and estimation of time series and cross section econometric models are discussed, as are their capabilities for obtaining long-run estimates of the net impacts of energy efficiency programs.

Introduction

Publicly-funded energy efficiency programs, as well as public policies and regulations, have grown in number, size, and scope throughout many countries over the past two decades. A major focus of these public efforts is on saving electricity, but substantial efforts have also gone into targeting energy efficiency for natural gas and petroleum use. The key issue that this paper addresses is how to determine, empirically, the extent to which public programs have influenced national trends in energy use. Credible quantitative estimates of public program effects are essential. Not only are they needed for financial accountability, for improving existing energy efficiency programs, and for designing future programs, but they are also needed for broad, long-range supply-side resource planning and national security planning.

When assessing government policies it is critical to bear in mind that they operate within functioning markets, not as independent, detached initiatives. This is particularly true with regards to publicly-funded energy efficiency programs that are targeted towards capital purchases and operations and maintenance services. After all, energy efficiency is just one product feature in a landscape filled with innumerable product features and characteristics, from miniaturization to multiple functionality. Thus, understanding how well public programs encourage the proliferation of a specific product feature such as energy efficiency – and consequently, how well they promote energy savings – necessarily requires a more general understanding of the dynamics of products and services markets.

Products and services markets. How is it that while the goal of energy efficiency programs is *energy savings*, the means by which these programs achieve their goals is *product sales*? The answer to this question is more involved than it may appear. It requires understanding what the first, best approach is to resolving negative externality problems, and what the second best approach entails – given that the first best approach is not acceptable for reasons political or otherwise. The compelling, and by now conventional economic argument that justifies publicly-funded energy efficiency programs targeted at consumers is that the prices consumers pay for purchasing energy are not the full marginal social costs of energy. This leads to over-production and over-consumption of energy.

The conventional argument is typically followed by the conventional solution, that is, to use market-based pricing mechanisms, such as Btu or pollution taxes, to increase energy prices and thus lower the quantity of energy consumed, However, this solution often leads to fierce political and institutional opposition, as well as opposition by those who argue that price mechanisms do not work properly in practice, especially for smaller users facing high information costs when reacting to high prices. Absent this approach, a second-best approach to discouraging energy use has become the international norm. It involves using public funds to promote, subsidize, or even require, increased energy productivity. To understand the ramifications of this second-best approach for program evaluation methodologies and research designs it is necessary to understand its conceptual origins.

The costs that energy producers or consumers impose on society at large without compensating affected parties are referred to as *negative externalities*. They occur because of the physically-damaging by-products of production and consumption, and they are viewed as an economic problem because they cause resources to be wasted. In the most general of terms, the inefficiency associated with negative externalities is displayed in Figure 1, in which the problem is viewed as originating with production.

In this illustration, S_1 is the marginal private cost curve that exists when producers do not pay for the costs they impose on society-at-large. At the market equilibrium associated with this supply curve, the quantity demanded is Q_1 and the price that consumers pay is P_1 rather than P_3; P_3 being the full marginal cost of production that includes private costs and societal costs. Were the price set at the correct marginal social cost of production, P_2 – which is at the intersection of the demand curve and the appropriate societal supply curve – the quantity demanded would be substantially lower, at Q_2. The most direct and effective methods for moving the quantity demanded to Q_2 is for the government to create tradable emissions markets, or impose taxes of some sort, that shift the marginal cost curve inward, from S_1 to S_2, and raise the market-clearing price to P_2. This new market equilibrium would represent an efficient use of resources.

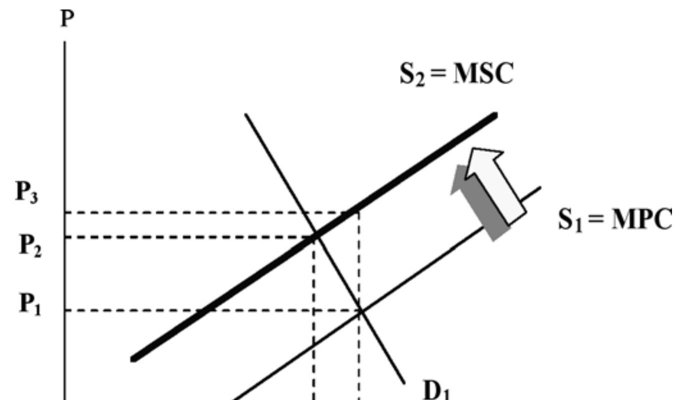

Figure 1. *Supply-Side Solution to Negative Externality.*

As illustrated in Figure 2, if policies that shift the supply curve are not possible, another method available to governments is to use consumer-oriented programs and policies to shift the demand curve for energy inward, to D_2 from D_1. Using this approach, energy prices appear to remain at P_1 while quantity moves downward to Q_2 from Q_1. Figure 3 illustrates that the energy demand curve, D_1 in Figure 2, is a composite of the demand schedules for various broadly-defined end uses that require energy for production, such as lighting, thermal comfort and food preparation. Thus, shifting the energy demand curve involves shifting one or more of the end use energy demand curves.

Hypothetically, the two different approaches could arrive at the same result. However, the demand-side solution is indirect, requiring successful public programs in many different energy-related markets rather than corrective pricing in the energy market itself. Moreover, it introduces additional complexity because energy demand is a derived demand, or an input, into the production of an end use service. Hence, shifting downward the end use demand for electricity involves some combination of shifting upward the demand for equipment that is energy efficient and shifting downward the hours of use of the equipment. The relationship between equipment efficiency choice, hours of use and energy demand can viewed as:

$$D_{kWh-enduse1} = \sum_{i=1}^{n} A_i R_i$$

where the demand for electricity for a specific end use, $D_{kwh-enduse1}$, is the sum of electricity consumed by the i^{th} piece of equipment, A_i, in conjunction with the individual hours of use or utilization rate, R_i, for that piece of equipment. The simultaneous nature of the demand for energy efficient equipment and the demand for the energy input that makes the equipment run can be separated into:

$$D_{A_i} = f(P_{A_i}, P_{A_j}, P_e, I, V);$$
$$D_{R_i} = g(P_e, I, W)$$

where the demand for the i^{th} piece of equipment, D_{Ai}, depends on its own price; the price of equipment alternatives, A_j; the price of electricity, P_e; income, I; and, a vector of appropriate variables, V. Likewise, the utilization rate, D_{Ri}, depends on the price of electricity, income and other appropriate variables, W. Figure 4 illustrates that the consumer-oriented public policy approach entails down-shifting the energy demand curve for one or more end uses and, in aggregate, causing the total demand for energy to move to D_2 from D_1. It is important to note that reducing energy demand for an end use service is not synonymous with reducing the demand for the end use service itself. The goal of the demand-side solution is energy productivity, which means using less energy to attain the same level of service, not using less energy by providing less service.

Economic justification for the consumer-oriented solution is little more than a variation of supply-side argument; end use energy demand is greater than it ought to be because electricity is underpriced, thereby causing equipment purchases and utilization rates to be sub-optimal. Also, the demand-side solution is a mirror image of the supply side solution vis-à-vis pricing and revenues. With the supply-side solution the majority of the marginal social costs levied on producers will eventually, because of the relative price inelasticity of demand, be passed along to consumers. With the demand-side solution consumers appear to be paying P_1 for their energy purchases when, in fact, somewhere along the line, either through taxes or tariffs, consumers are actually paying an additional cost of P_2 minus P_1 to fund programs that encourage them to increase their energy productivity. Under either approach, producer revenues are likely to be diminished by about the same amount.

The point of this discussion is to make clear that there is a symbiotic relationship between publicly-funded energy efficiency programs and the markets for energy efficient products and services. Consumption-oriented programs, which are used as second-best alternatives to solve the externalities problem that arises when energy prices do not reflect the true marginal social costs of production and consumption, do not operate in a vacuum. Rather, they operate within existing markets as one factor among many that jointly determine product sales volume, market share, prices, utilization rates, and so forth. This has important implications for program evaluation design, because it means that program evaluations must, as best as possible, control for all relevant market forces if they are to accurately measure program impacts. In econometric analysis, ignoring market forces is tantamount to denying their existence.

Distinguishing Program Impacts From Market Effects

There are many different research designs that can be employed to statistically distinguish between program impacts and market effects. One such research design was used for a study of the aggregate effects of publicly-funded programs on the market for fluorescent lighting ballasts. It involved estimating shipment demand and shipment market share equations for lighting ballasts for a control period from 1959 to 1980 and an experimental period from 1986 to 2000 (Marvin J. Horowitz, "Economic Indicators of Market Transformation: Energy Efficient Lighting and EPA's Green Lights." The Energy Journal, Vol. 22, No. 4, Fall 2001, pp. 95-122).

In the former period, the price elasticity of demand for high power-factor magnetic ballasts – where price was defined as the ratio of the price of high power factor magnetic ballasts to that of low power factor magnetic ballasts – was found to be approximately unitary. In the latter period in which public program promotion of new, energy efficient electronic lighting ballasts was pervasive, the price elasticity of the electronic ballasts – where price was defined as the ratio of the price of electronic ballasts to high power factor magnetic ballasts – was found to be larger by a factor of near-

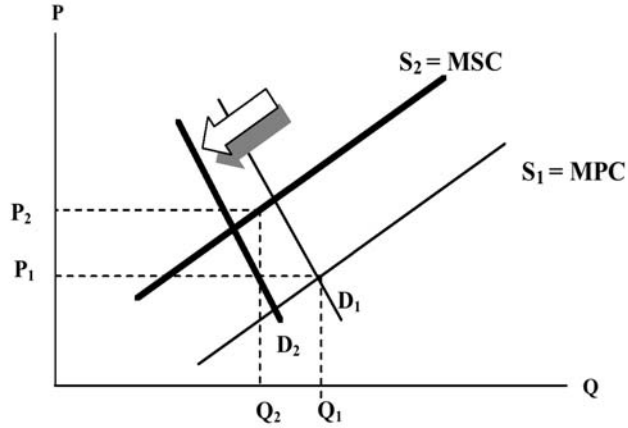

Figure 2. Demand-Side Solution to Negative Externality.

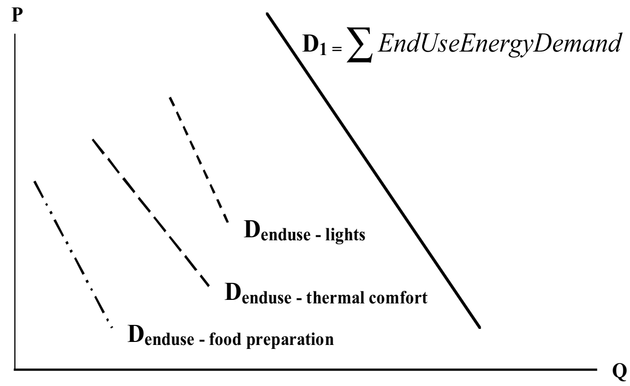

Figure 3. Total Energy Demand and End Use Energy Demand.

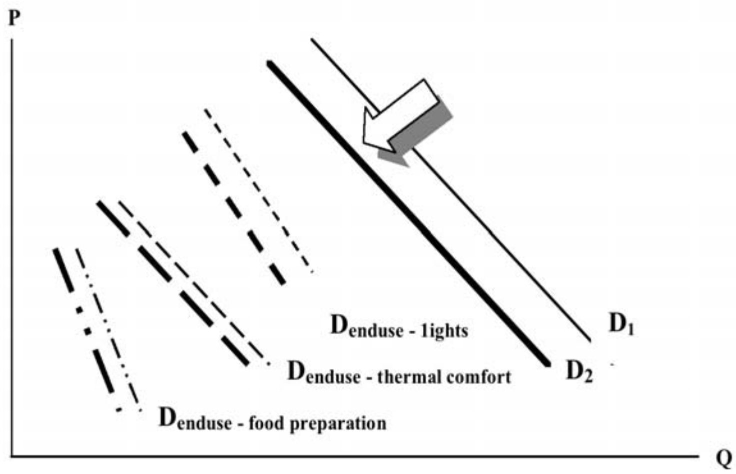

Figure 4. Downward Shift in Total Energy Demand.

ly four. This finding implied, all things being equal, that public programs from 1986 to 2000 had a substantial effect on how buyers of energy efficient lighting ballasts responded to ballasts prices. The magnitude of the program effect, captured by the ratio of the two price elasticities, implicitly incorporated free riders and spillover by controlling for market determinants such as energy prices and interest rates.

Analysis of products or services sales – be it by treatment-control, time series, cross section or panel research design -- is limited to measuring objects or activities, not energy savings. To measure the energy savings associated with products or services requires a secondary analysis using deterministic engineering models of end use service demand. These will be most accurate when there is little variation in product utilization rates, characteristics and wattages. However, there are alternative program evaluation approaches that avoid the shortcomings associated with this two stage analysis. They focus directly on energy use rather than on product or service sales and can be implemented when metered energy use is available for appropriate time intervals, geographic areas, and customers.

One example of this direct, empirical approach is a study that was designed to estimate the impact of public programs on U. S. commercial sector electricity use. It employed a panel model consisting of 42 states over the 13 year period, 1989 to 2001 (Marvin J. Horowitz, "Electricity Intensity in the Commercial Sector: Market and Public Program Effects," The Energy Journal, Vol. 25, No. 2, Spring 2004, pp. 115 – 137). In this study the dependent variable, state commercial sector electricity intensity, was constructed by dividing commercial sector electricity consumption by that portion of gross state product that can be attributed to the service sector, only – as opposed to the manufacturing, construction, agriculture, and mining sectors. By formulating the dependent variable this way, the analysis eliminates the confounding effects present in many studies, in which the structural shifts between the commercial and industrial sectors are overlooked. In addition, the estimated econometric model allowed for pre-existing, fixed differences between states, such as those that arise from different regulatory climates, different building codes, and other unobservable state-level differences that affect electricity use. The weighted least squares model is represented without the error term, with all continuous variables in log form, as:

$$EI_{i,t} = a_1 KWHP_{i,t} + a_2 NGP_{i,t} + a_3 HDD_{i,t} + a_4 CDD_{i,t} + a_5 GSP_{i,t} + a_6 FLOWADJ_{i,t} + a_7 INFOX_t + a_8 DSMX_{i,t} + a_9 MTX_t + a_{0,1} Z_1 + \ldots + a_{0,42} Z_{42}$$

where *i* represent the i^{th} cross section unit, and *t* represents the t^{th} time period. Except for the two national time trend variables, all the variables described below are measured at the state level: See Table 1.

Save for the construction of the dependent variable, and the two independent variables representing publicly-funded programs, i.e., *DSMX* and *MTX*, this model's specification – as well as its estimation – is fairly straightforward. In brief, *DSMX* is a state-level variable measured in physical units that represents the cumulative annual net kWh savings for commercial sector DSM programs, as reported by electric utilities to the U. S. Energy Information Administration on Form EIA-861. *MTX*, on the other hand, is a national-level energy savings indicator based on the cumulative number of shipped electronic ballasts in every year since their introduction in 1986.

The model findings indicate that from 1989 to 2001, controlling for market effects, the public programs lowered electricity intensity in the commercial sector by approximately 13.5 Wh/GCP. These impacts are displayed in Figure 5 in which actual average state electricity intensity is graphed along with what electricity intensity would have been each year in the absence of the public programs. The model projects that average state electricity intensity by 2001 would have been approximately 182.7 Wh/GCP when, in fact, the 2001 level of electricity intensity was approximately 169.2 Wh/GCP. This suggests that the observed annual reductions in electricity intensity through 2001 were due to public programs, and furthermore, that in the absence of public programs average electricity intensity would have increased 9.3 Wh/GCP, rather than decreased 4.2 Wh/GCP, from the 1989 baseline level. One interesting policy implication of this finding is that the stated priority of the National Energy Policy proposed by the Bush Administration in 2001 – of improving the future energy intensity of the U.S. economy – might not be possible vis-à-vis electricity in the commercial sector without the help of publicly-funded energy efficiency programs.

Another example of an econometric model that directly focuses on both market and program-related changes in energy use is designed for a study in which building-level microdata from around the U. S. is analyzed (Marvin J. Horowitz, work-in-progress). Using the U. S. Energy Information Administration's quadrennial, formerly triennial, Commercial Buildings Energy Consumption Survey (CBECS 1989, 1992, 1995, and 1999 – complete data for the 2003 survey are not yet publicly available), this study at-

Table 1.

EI	=	Wh sales per dollar of state gross commercial product (GCP)
KWHP	=	average price per kWh
NGP	=	average price per therm
HDD	=	annual heating degree days, weighted by population location
CDD	=	annual cooling degree days, weighted by population location
GSP	=	total gross state product
FLOWADJ	=	one period lag of EI
INFOX	=	national time trend of electronic business equipment production
DSMX	=	DSM savings per dollar state gross commercial product (GCP)
MTX	=	national time trend of market transformation activity
Z	=	state-specific dummy variables
a_1 - a_6, a_8	=	pooled cross sectional time series coefficients
a_7, a_9	=	time trend coefficients
$a_{0,1}$ - $a_{0,42}$	=	unique intercepts for each state

tempts to measure the determinants of annual electricity use while controlling for economic and program-related factors. Technically, this study is not a panel or an experimental-control design (different buildings are questioned in each survey – except for 1999 where, to save on survey costs, a subset of buildings was revisited), nor a time series design (there are two few survey years and they are not continuous or at regular intervals). It bears closest resemblance to a cross section study, except that in addition to static factors there are time-related variables that affect each survey cohort differentially. The preliminary model is in logs, and suppressing the error term, takes the form:

$$\begin{aligned}KWH_{i,j,k} &= b_1KWHP_{j,k} + b_2SQFT_i + b_3FLOORS_i + b_4FUEL2_i + b_5FUEL3_i \\ &+ b_6HDD_i + b_7CDD_i + b_8NWKER_i + b_9WKHRS_i + b_{10}MANUFACT_i \\ &+ b_{11}GOVERN_i + b_{12}OWNOCC_i + b_{13}\%HEAT_i + b_{14}\%COOL_i \\ &+ b_{15}HEATOFF_i + b_{16}COOLOFF_i + b_{17}VACANCY_i \\ &+ b_{18}INFOX_k + b_{19}DSMXD_{j,k} + b_{20}D99_k\end{aligned}$$

where *i* represents each of 22 509 individual buildings, *j* represents each of the 9 census divisions, and *k* represents each of the 4 CBECS survey years, and see: Table 2.

In this model, building-level market-related effects are controlled for by incorporating into the model several variables that describe energy consumption behaviour and the physical characteristics of the building. However, electricity prices at the building level are not available and constructing an average kWh price per building by dividing a building's energy bill by kWh usage, while a reasonable practice at the aggregate level, creates an endogeneity dilemma at the micro level. Hence, a census division-level electricity price variable is constructed, by year, based on total divisional electricity revenues and consumption. To capture the technological change that occurred in business operations from 1989 to 1999, a national index of electronic business equipment is included in the model.

Once market-related effects are controlled for, public program-related effects must be addressed. To do so, two public program variables are incorporated into the model. The first, *DSMXD*, is a census division-level variable that is, as described above, measured in physical units and reported by electric utilities on Form EIA-861, divided by the respective census division's gross commercial product. The regression coefficient of this variable captures the DSM effect. However, it does not capture the effect of market transformation programs; this effect is more recent that the DSM effect and should, in theory, be captured at the national level and manifested by a downward shift in the energy consumption curve. To detect this shift, the model is completed by a dummy variable, *D99*, that differentiates the latest year of the CBECS survey from the earlier years.

The preliminary findings of this analysis are encouraging. Most of the market-related coefficients take the expected signs, are of reasonable magnitudes, and have relatively small standard errors. For example, the electricity price variable indicates that demand is price inelastic – a 10 percent change in price leads to a 2.5 percent change in quantity demanded. Also, the 3 month vacancy variable indicates that this is associated with a decrease in annual electricity use of 20 percent. With respect to public programs, although the DSM variable is not statistically significant, it indicates that DSM did lower electricity use. Finally, the dummy variable for the final survey year indicates that a shift in electricity consumption did occur in this year relative to the earlier years – overall, electricity use declines by approximately 8 percent relative to the earlier years. This effect is statistically significant.

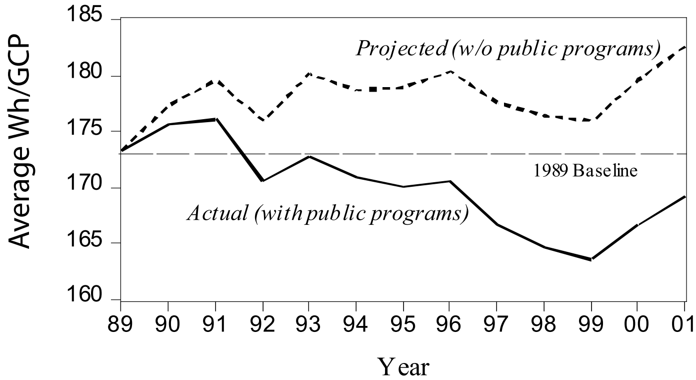

Figure 5. *U. S. Commercial Sector Electricity Intensity.*

Table 2.

KWH	=	annual, non-weather adjusted electricity consumption
KWHP	=	average price per kWh
SQFT	=	building square feet
FLOORS	=	number of building floors
FUEL2	=	dummy variable if building uses natural gas
FUEL3	=	dummy variable if building uses oil or steam
HDD	=	annual heating degree days (masked)
CDD	=	annual cooling degree days (masked)
NWKER	=	number of full-time workers
MANUFACT	=	dummy variable if kWh-based manufacturing occurs on site
GOVERN	=	dummy variable if building owned by any government
OWNOCC	=	dummy variable if building is owner-occupied
%HEAT	=	percent of the building that is heated
%COOL	=	percent of the building that is air conditioned
HEATOFF	=	dummy variable if heat is turned down during off-hours
COOLOFF	=	dummy variable if cooling is turned down during off-hours
VACANCY	=	dummy variable if building was vacant more than 3 months
INFOX	=	national time trend of electronic business equipment production
DSMXD	=	DSM savings per census division gross commercial product
D99	=	dummy variable for 1999 CBECS sample
b_2 - b_{17}	=	cross sectional coefficients
b_1, b_{19}	=	census division, time-specific coefficients
b_{18}, b_{20}	=	time-specific coefficients, only

Gross and Net Impacts

One of the unfortunate consequences of evaluations that do not adequately control for market effects is that their findings must often be corrected through processes that transform the estimates from *gross* to *net* savings. Often this is done by estimating a *net-to-gross* ratio or estimating a *realization rate*. The distinctions between gross and net savings, or expected versus actual savings, have many implications that affect both the quality and cost of impact evaluations. Three elements that are crucial to the concept of net savings are particularly pertinent to this research findings presented in this paper.

First, the possibility of an actual or potential market for an energy efficient product implies that an energy efficiency program could suffer from free ridership, or more broadly, adverse selection. Depending on how adverse selection is treated it either drives up program costs or lowers program benefits – in either case, lowering program cost-effectiveness. Indeed, a qualitative estimate of free ridership rates based on three decades of program evaluations might be in the neighbourhood of 25 percent. To derive individual program free rider estimates, conventional impact evaluations require costly telephone survey to be conducted in parallel to the main impact analyses. However, for the econometric models described above, the expenses and troubles of surveying for free ridership are avoided. Free ridership is implicitly controlled for with no need for a stand-alone estimate based on self-reported hypothetical behaviour.

A second related issue, referred to as "spillover," raises program benefits and increases program cost-effectiveness. Spillover is a program benefit that occurs when a program's influence inadvertently exceeds its geographic or temporal boundaries. Typically, like free ridership, to measure spillover additional data collection and analyses must be commissioned. However, a market demand model of product sales that is fully-specified will be capable of yielding a coefficient, or set of coefficients, that quantify *net* program impacts – rendering unnecessary additional and costly research efforts. Again, the econometric model helps avoid the need for stand-alone estimates based on self-reported hypothetical behaviour.

A third and final market-related factor that affects net impact estimates is referred to as "rebound." Rebound occurs when higher equipment efficiency levels lead to increased hours of use or utilization rates – in other words, to an increase in the quantity demanded of end use services. This phenomena is expected because microeconomic theory predicts that a decrease in the price of an end use service will, all things being equal, lead to an increase in the quantity demanded of the service. Nevertheless, rebound is frequently ignored in program planning and program evaluations, often because its effects are considered too small to be concerned with. Fortunately, rather than assume that rebound is effectively zero, econometric models of energy demand directly, if implicitly, incorporate this effect into their estimates. Once again, difficult and unreliable stand-alone estimates are rendered unnecessary.

An indication of the overall unreliability of conventional energy efficiency program impact evaluations is derived from the findings in Horowitz (2004). Using the energy savings impact estimate from the U. S. commercial sector electricity intensity model, an aggregate DSM program *net* realization rate was calculated to be 54 percent. This net realization rate represents the percentage of utility-reported DSM savings from Form EIA-861 that is confirmed by an empirical analysis of retail electricity sales. Since electric utilities presumably reported *net* DSM savings, this finding suggests that even when electric utilities undertook separate costly surveys to derive net savings, energy savings were, on average, overstated by almost double.

Conclusion

This paper began by arguing that a symbiotic relationship exists between publicly-funded energy efficiency programs and the markets for energy efficient products and services. For energy efficiency programs the major implication of this argument is that evaluations must control for relevant market forces if they are to accurately measure program impacts. In support of this assertion, this paper briefly described key elements of three econometric studies. Each provides empirical evidence that market forces cannot be ignored in studies that are intended to analyze energy consumption and energy efficiency.

Program evaluations that downplay the importance of markets are likely to overstate program successes. For the majority of goods and services that publicly-funded energy efficiency programs promote, markets do exist, can exist, and will exist -- albeit they may be small or specialized. Prima facie evidence of the acceptance of this reality by those who implement programs is the fact that program evaluators, managers and regulators, spend a great deal of time and effort attempting, after the fact, to understand and measure market effects such as program free ridership, spillover, and rebound.

If markets for products and services that are energy efficient can or do exist, any objective, quantitative analysis of program impacts must begin with careful consideration of these market and their determinants. In practical terms, this involves specifying and estimating an econometric model that contains all of the key variables that drive market demand, including prices, incomes, and related trends. In other words, energy efficiency program evaluations should not be much different than any other comparative static or dynamic study of market supply or demand, the one oddity being the necessity to modify the research design to test for, and quantify, public program effects.