# New Analysis Techniques for Estimating Impacts of Federal Appliance Efficiency Standards

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## Abstract/Introduction

Impacts of U.S. appliance and equipment standards have been described previously [1]. Since 2000, the U.S. Department of Energy (DOE) has updated standards for clothes washers, water heaters, and residential central air conditioners and heat pumps [2, 3, 4]. A revised estimate of the aggregate impacts of all the residential appliance standards in the United States shows that existing standards will reduce residential primary energy consumption and associated carbon dioxide ($CO_2$) emissions by 8–9% in 2020 compared to the levels expected without any standards.[5] Studies of possible new standards are underway for residential furnaces and boilers, as well as a number of products in the commercial (tertiary) sector, such as distribution transformers and unitary air conditioners. [6]

The analysis of standards has evolved in response to critiques and in an attempt to develop more precise estimates of costs and benefits of these regulations. The newer analysis elements include: (1) valuing energy savings by using marginal (rather than average) energy prices specific to an end-use; (2) simulating the impacts of energy efficiency increases over a sample population of consumers to quantify the proportion of households having net benefits or net costs over the life of the appliance; and (3) calculating marginal markups in distribution channels to derive the incremental change in retail prices associated with increased manufacturing costs for improving energy efficiency.

## Valuing Energy Savings by Using Marginal Energy Prices

For valuing energy costs and savings in the residential sector, previous analyses evolved from using national average prices to using average energy prices for individual households in a national survey, the Energy Information Administration's Residential Energy Consumption Survey (RECs). In April 1998, DOE's Advisory Committee on Appliance Energy Efficiency Standards recommended that DOE should replace the use of national average energy prices in LCC analyses with the full range of consumer marginal energy prices. DOE subsequently used marginal energy prices in the analysis of standards for fluorescent lamp ballasts [7], residential central air conditioners [4], room air conditioners and water heaters [3].

Determining the marginal value of the energy saved involves calculating the customers' energy bills before and after an energy efficiency increase. The change in the energy bill accurately captures the marginal value, because consumers save energy on the margin (that is, at the price they pay for their last units of energy), rather than at the average price they pay for their energy. Unfortunately, neither published nor readily available data existed for consumer marginal energy prices. The marginal value depends upon the total bill prior to standards, which is a function of the tariff structure and total energy usage. A major research effort was required to derive a representative distribution of consumer marginal energy prices.

Because electricity and natural gas tariffs tend to have both fixed and variable charges with either inclining or declining rate structures, and because seasonal differences in rates are common, marginal prices and average

prices are different for most households. That is, marginal prices are not related to average prices in a simple, direct manner; they cannot be accurately estimated by simply determining the proportion of energy bills that are represented by fixed costs. Instead, deriving seasonal marginal prices for a household requires knowing the household's monthly energy bills and consumption for at least one year. Since the slope of the line that relates the household's energy bills and energy consumption for a season is an estimate of the household's marginal price for that season, deriving the slope of that line provides an estimate of the marginal price. A linear regression fitting the best line to the season's bills and consumption levels provides that slope.

RECS provides household billing data for a nationally representative sample of households, monthly for at least a year.[8] We estimated consumer marginal energy prices in the residential sector from the 1997 RECS monthly billing data by calculating linear least-squares regression models relating customer bills to customer energy consumption for each household for which billing data were available. We interpreted the slope of the regression line for each household as the marginal energy price for that household for the season in question.

Our analysis resulted in estimates of national mean seasonal electricity and natural gas marginal prices that were less than average prices, on a weighted household basis. As national averages, marginal electricity prices in summer were 2.5% below annual average prices, while non-summer marginal electricity prices were 10% below annual average prices. Marginal natural gas prices averaged 4.4% below average natural gas prices in winter, and 15% below in non-winter. The marginal prices vary for each product, depending upon the load shape, tariff structure and seasonality of use. For air conditioners (residential or commercial), the marginal electricity price is higher than the average price, while for commercial lighting, the marginal electricity price is similar to the average price.

For use with estimates of the annual energy savings associated with more efficient equipment, we aggregated the seasonal marginal prices into an annual value. We used the seasonal-weighted energy consumption of the particular end-use to arrive at an annual price. For air conditioning, the summer marginal price is more heavily weighted in the determination of the annual marginal price. For some end-uses, such as clothes washers, monthly energy use does not change significantly over the course of a year. In that case, the seasons are simply weighted by their number of months. For water heaters, we used monthly allocation factors derived from field studies that measured monthly energy consumption.

The future direction of research on marginal value of energy savings is to study tariff structures in relationship to end-use load shapes. The most detailed analyses use hourly pricing and hourly energy savings.

## Differences Among Consumers: Simulating Impacts of Standards Across a Sample Population of Consumers

Economic impacts from standards differ among households for many reasons including purchase behaviors, energy prices and usage behaviors. In recent years, U.S. analysis has moved away from use of average values and implemented a method to estimate the impacts over the full range of consumer conditions.[9]

Using a valid sample of consumers is especially important for space conditioning appliances, since the energy consumption is affected by climate and building characteristics as well as consumer behavior. The analysis recently conducted for residential furnaces provides an example of how to simulate the impacts of potential standards across a sample population of consumers.

To estimate the impact of design options across a wide range of households that use furnaces and boilers, we selected a sample of households from the 1997 RECS survey of over 5000 households. For each sampled household, we simulated the energy consumption of furnaces and boilers twice, incorporating first a baseline (no new standard) design and then a higher efficiency design. For each sample household, we calculated what the household's LCC would be if its furnace or boiler were of a particular design. We matched the size of the equipment allocated to each household with the size of the house and the climate in which the household is located.

To account for the uncertainty and variability in the inputs to the LCC calculation for a given household and between different households, we defined a distribution of values for each input, rather than a single average value. The distribution represents the range of possible values with each value having a probability. The probabilities (weighting) attached to each value account for variability from household to household and for uncertainty. A value is drawn from each input distribution by random sampling (Monte Carlo). As a result, the simulation analysis produces a range of LCC results rather than single-point values. The range of results can be interpreted in terms of the fraction of the population having particular results. For example, a distinct advantage of this approach is the ability to identify the percentage of consumers achieving net LCC savings (or net costs) or attaining certain payback periods due to an increased efficiency standard. The average and median LCC savings or payback period for that standard are also calculated.

For each product class, the analysis calculates the LCC and payback period for 10,000 trials in each Monte Carlo simulation. For each of the 10,000 trials, the analysis samples from the distributions of input values. For some variables, such as energy price and climate, each trial uses the values that are associated with a particular house that participated in the survey, effectively accounting for the correlation between those variables. For these variables, the model samples from the set of houses according to the weighting that the survey assigned to them. This weighting is designed to reflect the prevalence of various features in the total population of houses. Sampling according to the weighting means that some of the houses are sampled more than once, and others may not be sampled at all.
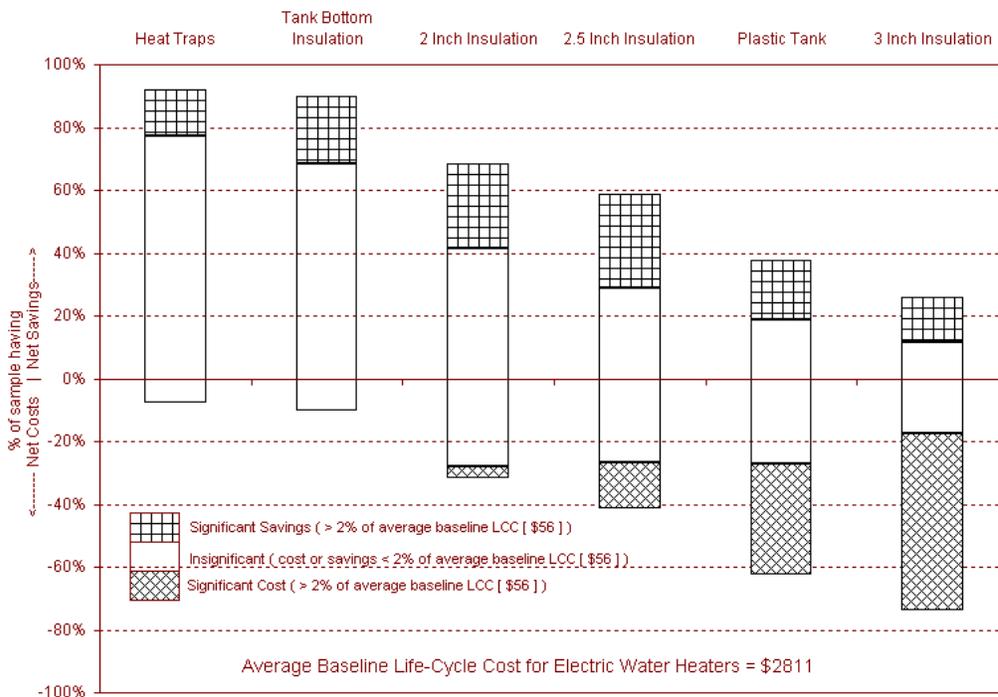


FIGURE 1. PERCENT OF SAMPLE HAVING NET LIFE CYCLE SAVINGS OR COSTS FOR SIX DESIGN OPTIONS RELATIVE TO A BASELINE DESIGN.

Figure 1 shows the percent of the sample of households having net savings or net costs in life cycle cost for a set of design changes that would increase energy efficiency. For each design, the bar's height above the horizontal axis (positive value) shows the percent of the sample that would have net savings. Conversely, the portion of the bar below the horizontal axis (negative value) shows the percent of the sample having a net life cycle cost increase. The bars are segmented into three sections: significant savings, no significant change, and significant costs. Net costs or savings were deemed significant if they exceeded $56, or 2% of the average baseline LCC.

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We used Microsoft Excel spreadsheets with Crystal Ball®, an add-on software, to perform the Monte Carlo analysis, but other software products perform the same function.

The Monte Carlo method provides a more comprehensive picture of not only the average or median impact on households, but also the range of variation in impacts among customers and the fraction of households likely to attain net benefits (or net costs) from the standard. The systematic accuracy of the analysis for which the Monte Carlo simulation is used depends on accurately characterizing the range of input values for each variable and for accounting for correlations among the inputs. Statistically, the degree to which the results of the simulation represent the full range of possible outcomes depends only on the sample size, and can be judged using standard statistical techniques

## Future Equipment Prices: Calculating Markups Appropriate for Incremental Changes in Manufacturing Cost

A key challenge in standards impact analysis is estimating the future consumer price to expect for higher-efficiency appliances resulting from efficiency standards. When standards are enacted, the manufacturing cost of appliances is likely to rise. Engineering cost estimates by manufacturers, taking into account expected production volumes, are a common means for estimating the costs to manufacture. Applying a markup consistent with previous industry experience gives the price at which manufacturers sell to distributors and wholesalers, the manufacturer price. In order to estimate the impact of the standards on consumers, analysts must determine how much the consumer price of the appliance will rise as a result of this increase in manufacturer price. The incremental change in consumer price associated with a change in manufacturer price is termed the "incremental markup." The incremental markup depends upon how products are distributed from manufacturer to consumer and typically includes markups by wholesalers, distributors and, in some cases, contractors.

There seem to be two approaches for estimating the incremental markup: an easy but less accurate strategy and a more complicated but more accurate strategy. The easy approach is to assume that incremental markup is equal to the ratio of consumer price to manufacturer price of equipment sold prior to enacting the standard. For example, if an existing appliance is sold to the consumer for $600 and costs $300 to manufacture on average, the average markup on that equipment is 2.0. The average markup reflects the costs of retail/wholesale storage, marketing and transport. It is relatively easy to apply this average markup to estimate the rise in the consumer price resulting from efficiency standards. If the standard is expected to increase manufacturing price $30, the rise in consumer price ($60) can easily be calculated as the product of the incremental manufacturing price ($30) and the average markup (2.0).

The easy approach is likely to overestimate the impact of standards on consumer prices, because of the implicit assumption that the retail and wholesale costs necessarily rise in proportion to manufacturer price— that a 10% rise in manufacturer price necessarily implies a 10% rise in retail and wholesale costs (and thus the consumer price). In contrast, our evaluation of the data suggests that many retail and wholesale costs are fixed and independent of changes in manufacturer price. A more accurate approach is to evaluate in detail which wholesale/retail costs will change after a standard increases equipment efficiency and which remain fixed.

Some wholesale/retail costs are likely to increase when appliance efficiency goes up. For example, the cost of insuring and financing more expensive equipment is likely to be higher than the same costs for less expensive equipment. Other costs, including labor and occupancy costs, are not likely to increase when appliance efficiency goes up. That is because equipment that is similar in size and weight over a range of efficiencies requires no more labor or storage space to handle efficient equipment than is needed to handle inefficient equipment. If size or weight change sufficiently, then labor, storage and transportation costs may also change.

We estimate the incremental markup by including only costs that increase with manufacturer price in the markup, unless product characteristics (size, weight) change in going from less efficient to more efficient products.

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This analysis requires detailed data on costs in the relevant economic sectors. For the residential furnaces standards analysis, for example, the wholesale heating, ventilation and cooling (HVAC) markup is based on firm balance sheet survey data obtained from the trade associations representing HVAC wholesalers. These balance sheets break out the components of all costs incurred by wholesale firms that handle HVAC equipment. These wholesale costs can be divided into two categories: 1) costs that vary in proportion to a rise in the manufacturer price (variable costs) and 2) costs that do not vary with the manufacturer price (fixed costs). Information obtained from the trade literature indicates that wholesale and contractor markups vary according to the quantity of labor and materials used to distribute and install appliances, with markups on labor tending to be much larger than markups on materials. In addition, markups are described as varying much more in relation to sales volume than other factors, including appliance efficiency.

In practice, this approach gives an incremental markup that is different, and usually lower, than the baseline markup. For HVAC wholesalers, we estimated the baseline markup as 1.36, and the incremental markup as 1.11.

## Conclusion

This paper has described three analytical techniques that have been used to bring greater accuracy to the estimation of impacts of possible standards:

(1) Valuing energy savings by using marginal (rather than average) energy prices specific to an end-use. Marginal prices depend upon the load shape of the end use, the tariff structure, and the seasonality of use. Marginal prices can be derived for each customer from the slope of billing data or by using the tariff structure and energy consumption to simulate the effect of energy efficiency improvements on energy bills.

(2) Simulating the impacts of energy efficiency increases over a sample population of consumers to quantify the proportion of households having net benefits or net costs over the life of the appliance. Impacts of standards vary among customers. Characterizing the range of impacts and the fraction of households having net costs or net savings provides more complete information into the policy decision.

(3) Calculating marginal markups in distribution channels to derive the incremental change in retail prices associated with increased manufacturing costs for improving energy efficiency. Some wholesaler, distributor and contractor costs, such as some labor, storage and transportation costs, are independent of the efficiency and price of the appliances. In these cases, increasing the efficiency and price of an appliance has a less than proportional impact on consumer price. The marginal markup from manufacturer price to consumer price when efficiency increases is often less than the current ratio of consumer price to manufacturer price.

These methods are being researched in analysis of potential updates to standards for appliances.

## Acknowledgement

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