Econometric Modeling of the Effects of Energy Efficiency Standards on Appliance Shipments

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ABSTRACT

Cost-benefit analysis of appliance energy efficiency standards requires an estimate of their impact on appliance shipments. This paper presents details of a shipment forecasting technique for appliances. The modeling method provides a dis-aggregated accounting of household decisions related to purchase, repair and replacement of appliances by fuel type and age group. The model contains a component for keeping track of appliance stock and vintage, and a component for modeling consumer decision-making. Consumer choice is modeled with a logit decision probability function whose econometric parameters are calibrated to historical trends. Inputs to consumer decision-making include appliance retail and installation costs, as well as forecasts of macroeconomic variables such as household income and housing construction. In this way, dis-aggregated shipments are forecast through the period 2003 to 2030. The method provides an explicit quantitative approach to modeling regulatory impacts. Furthermore, it demonstrates a generic framework that can be applied to a wide range of appliances and policy initiatives.

Introduction

Enhancing information and predictability regarding the impacts of potential energy efficiency standards opens up new opportunities for energy savings and national economic benefits. In this paper we show how dis-aggregated appliance stock and household accounting models that include probabilistic consumer decision models can be used to enhance appliance market forecasts. These enhanced market forecasts can then be used to analyze future impacts of new energy standards and regulations.

Political players in the energy efficiency debate often treat energy efficiency standards as a zero-sum game. 'If energy is to be saved,' they argue, 'then there are going to be extra costs, and someone (probably American business) is going to bear those extra costs.' In fact, while standards may be a zero-sum game in some circumstances, in many situations they may result in a win-win situation. A win-win situation is one in which a change in the rules of interaction, allow all players to enhance the benefits they receive.

Lack of information can prevent consumers from making purchase decisions in their best interest. Therefore, appropriate energy efficiency standards can resolve information distribution imperfections in the market place. For example, if an appliance saves $40 over the long term, and if mean wages are approximately $13 per hour in the U.S. (the 1999 value), then the average consumer cannot spend more than three extra hours researching and calculating benefits from energy efficiency. Spending more time than this would incur costs in excess of the efficiency benefits. For consumers with no expertise in the field, and a healthy skepticism of sales people and government information, it remains in their self-interest to stick with well-known, inefficient appliances.

Standards resolve efficiency-related information imperfections by doing the calculation once, for everyone, with controls and inputs from a diversity of stakeholders.

Once this market imperfection is resolved there are potential benefits that accrue to utilities, manufacturers and consumers. For utilities, the decreased consumption means that consumers are spending a greater fraction of their energy budget on connection and fixed costs which are provided by the utility, rather than variable costs which result from fuel prices over which the utilities have less control. It also means that utilities can satisfy consumer demand without expensive new capacity expansions. This provides for the potential of higher returns and growth for the consumer services provided by the utility. For appliance manufacturers, they receive enhanced opportunities for marketing higher quality and higher priced appliances, since consumers can exchange operating cost savings for higher appliance prices. The higher appliance prices may allow for greater revenue growth in appliance sales. The increased dollar sales volume provides for greater profit and industry growth potential. Whether the profit potential is realized depends on the detailed balance between required investments and price markups used to recover these investment costs, and may be constrained by key actors in distribution including retailers and consumers. For the consumer, the reduction in energy bills can more than offset the higher appliance prices resulting in net consumer benefits over the life of the appliance.

However, choosing the optimum win-win efficiency level requires accurate forecasting of the impacts of standards on consumers, manufacturers, and utilities. As standards impact forecasts are developed, diverse detailed questions are raised regarding many aspects of the market changes induced by standards. It is therefore necessary to have detailed forecast models that can resolve these questions for a diversity of stakeholders and interests.

This paper presents forecast modeling strategies that provide detailed and robust forecasts given the constraints of limited available data. The forecasts also provide insight into long-term market changes that can affect standards impacts.

Model Overview

In developing an economic forecasting model there are trade-offs between the complexity of the model, the data requirements of the model and the detail and accuracy of the model predictions. The first two factors, complexity and data requirements, contribute to the costs of the modeling effort, while detail and accuracy are beneficial qualities of the final product. The modeling approach described here attempts to optimize the trade-off between modeling costs and benefits by using two strategies. The first modeling strategy is compartmentalization and dis-aggregation of market quantities and dynamics. This allows the enforcement and specification of a larger number of constraints and conservation rules on the economic dynamics that decreases the sensitivity of model outputs to assumptions and errors in input parameters and data. The second modeling strategy is to provide explicit explanatory decision models for consumer behavior with a minimum of free parameters. This allows forecasts to describe explicitly the different assumptions of the decision modeling, and to calibrate the model to historical data vis-a-vis a limited parameter set. Even when there is not consensus on the details of how consumers make decisions, at least the consequences of different assumptions can be examined to provide a range of reasonable outcomes.

The procedure for model formulation proceeds in three stages:

1. Definition of the events and consumer decisions that can lead to appliance purchases.
2. Segregation of households into categories that are subject to the different sets of decisions and events.
3. Formulation of the probability functions that describe events and decisions with regards to the disposition or purchase of appliances. The functions may have a dependence on explicit economic variables.

Different appliances are subject to different events and decisions, but a list of the most common set of events and decisions that can impact new appliance sales can be compiled:

1. Does the appliance develop a problem that warrants some action (e.g. repair or replacement)?
2. Should the appliance be repaired or replaced?
3. Is the consumer moving into a new house that needs a new appliance?
4. Is the consumer making a change of residence into an existing house that either needs a new appliance or where replacing an old appliance is convenient and advantageous?
5. Should the appliance be replaced with a new or used appliance?
6. Is the consumer tired of doing without the appliance and should they change their status from a non-owner to an appliance owner?
7. Even though the appliance should be replaced, are new appliances so expensive that the consumer is willing to have the current one rebuilt, extending its normal lifetime?
8. Shall the appliance be replaced early because of remodeling or simply the desire for an updated version of the appliance?

For some appliances, some of these decisions and events will not be significant or relevant, while for other appliances nearly all of these decisions can have significant impacts on sales.

In addition, because the probability of many of the events and consumer decisions depends on the age of the appliance, it is in general necessary to keep track of each age category of an appliance in such an accounting model. It is also necessary to formulate age-dependent probability functions for most of the events and consumer decisions.

Model Details

In this section some of the details of the implementation of the above model are described. The main issues in the construction of a dis-aggregated accounting model are the following: (1) How does one select the right combinations of explanatory economic drivers and explanatory variables? (2) How does one formulate the event and decision probability functions?

We discuss these in turn below:

Economic Drivers and Decision Parameters for Appliance Sales

There are several different drivers to appliance sales that operate at different stages of the appliance introduction and adoption cycle. During the very early stages of appliance introduction, very few households have access or the capability of purchasing the appliance that may be either new, or very expensive. But after the market accepts an appliance, the market becomes saturated and nearly all households are using the services of the appliance one way or another at its particular level of adoption. After market acceptance and saturation the dynamics of repair needs, replacement decisions, and housing changes appear to dominate the market dynamics.

Housing. Housing starts (new housing) and the dynamics of change of residence appear to dominate short-term fluctuations in appliance sales that occur over periods of several years. Figure 1 compares total clothes washer sales (including both automatic and wringer washers) with new housing completions. It can be seen from the figure that there is a close correlation between fluctuations in new housing completions, and short-term fluctuations in new clothes washer sales. The amplitude of the clothes washer sales fluctuations is larger than the fluctuations in new housing completions. This can be explained if there is other economic activity correlated with new housing completions such as remodeling activity, or changes of residence that provide opportunities for remodeling and extra appliance purchases.

Non-Residential Construction, Additions, Remodels, and Changes of Residence. According to the 1997 Economic Census, while there was approximately $204 billion in new residential construction, there was also $46 billion in residential additions and alterations, and $26 billion in residential maintenance and repair. In addition, there was $441 billion in total new building construction, $160 billion in additions and alterations of existing buildings, and $67 billion in maintenance and repair. This large volume of economic activity related to new home construction provides evidence for moves into additions, alterations, and new small-scale offices that can prompt new appliance sales in ways similar to new housing construction. In our modeling approach we therefore include an additional appliance market with sales correlated to new residential housing completions.

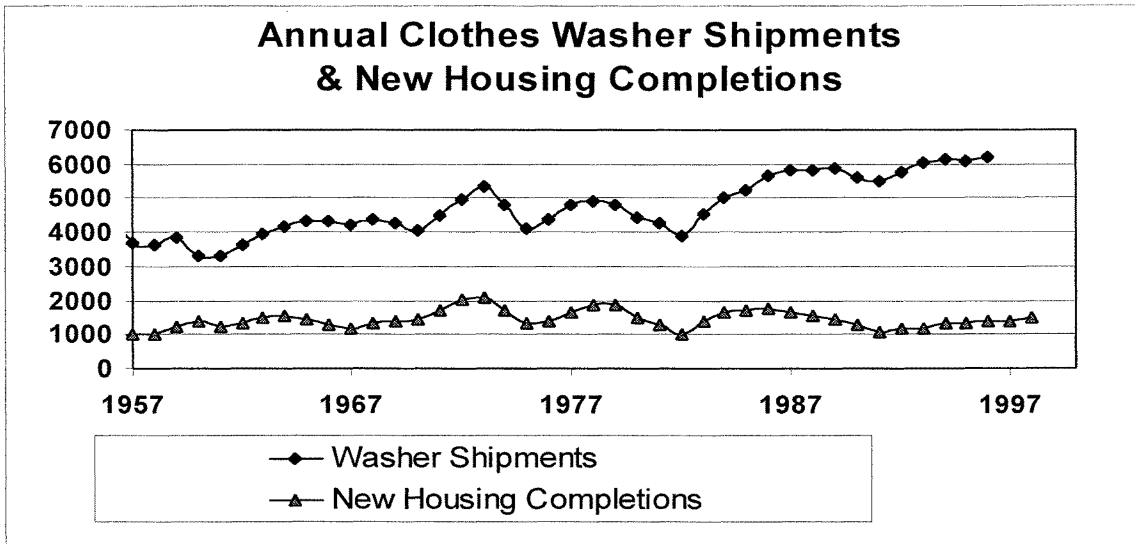

Figure 1. Comparison of total clothes washer shipments and new housing completions 1957 to 1997.

Price & Operating Cost Savings. Energy efficiency standards tend to effect the purchase price and operating costs of the appliances on which they are imposed. Therefore an essential component of models that forecast the effect of standards is calibrating price and operating costs impacts on long-term purchase behavior and trends.

Figure 2 shows long-term price trends for two appliances and for fuel and utilities in constant inflation-adjusted dollars where the Consumer Price Index is used to measure inflation. In the figure we show an inflation-adjusted price index where the index is fixed at 100 for 1997. We see from the figure that while there are very similar long-term price trends for the two appliances, fuel and utility costs are roughly constant in inflation-adjusted dollars. In contrast, the over-all trend in appliance prices is a long-term inflation-adjusted price deflation of 2% per year. This means an assumption of constant real appliance prices (a typical assumption in many analyses) may overestimate future appliance price trends.

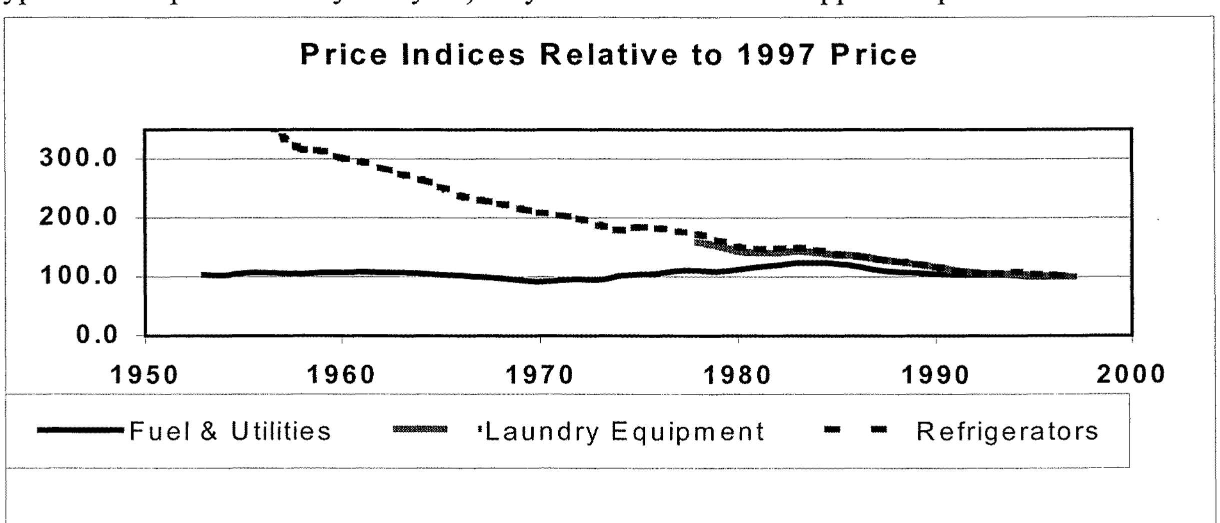

Figure 2. Constant dollar price trends for utilities and appliances.

The long-term trends have important implications with regards to utilizing historical trends in sales to calibrate the parameters of the consumer decision probabilities. While there is a consistent trend in purchase price that can be correlated with long-term trends in consumer purchase decisions, fuel and utility prices have no such trends. We therefore use other information sources to estimate the relative importance of price and operating cost savings. The other sources we use for estimating how consumers value energy costs include intercept surveys, relative market shares of efficient appliances, or the results of consumer conjoint analyses. We express this relationship between price and operating cost influences in terms of a market discount rate for the consumer evaluation of operating cost savings. We obtain estimates for the consumer market discount rate that range from 100% (one year payback) to 20% (five year pay back).

Income. Figure 3 shows the long-term trends in real household income from 1947 to 1997. The trend in income corresponds to a 100% real increase during this period with three major dips corresponding to the economic recession/expansion cycles of the latter half of the period. The dips in household income correlate well with dips in new housing starts since income relates to consumers' ability to pay for new housing. We therefore find that income trends are correlated with a combination of price trends and housing starts. This means that if we can explain one pattern of shipments by correlating it with income, we could also explain it by correlating it with price and new housing starts and visa-versa. Therefore the relative role of income as compared to price and housing starts must be derived from information exogenous to the historical appliances shipments data.

Event and Decision Probability Functions

Now that we are familiar with the behavior of different candidate explanatory parameters for consumer purchase behavior, we review the decision models and probability functions that are used to describe this behavior.

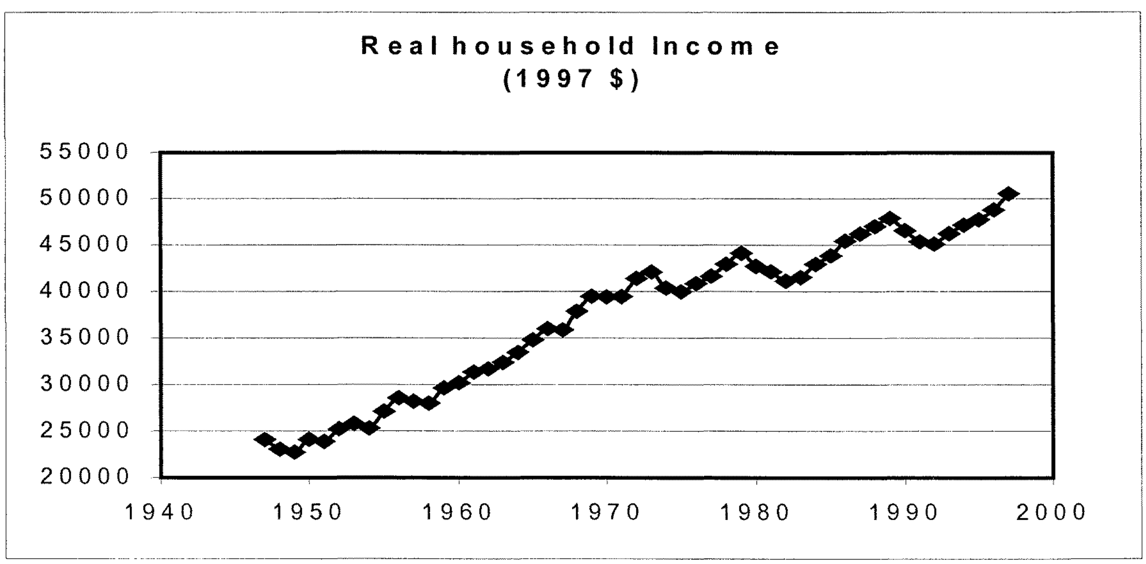

Figure 3. Average real household income.

Our mathematical building block for the modeling of consumer decision probabilities is the binary logit probability of purchase model. In this model, the probability of purchase depends on the utility of the appliance, U, which depends on the attributes of the appliance. This purchase probability is constrained to be between 0 and 1, and relative changes in the probability of purchase are proportional to changes in the utility of the appliance. Requiring that the probability of purchase function satisfies the following equation can satisfy these theoretical requirements for the decision probability function:

dProb/Prob = dU * (1-Prob)

Where Prob = decision probability, and dU is the differential change in utility which often is a linear function of the appliance attribute variables (e.g. $U = U_0 + A * (Price-Price_0)$, where A is a price coefficient). The factor of (1-Prob) on the right hand side of the equation enforces the condition that the probability of purchase never exceeds 1. Solving for Prob as a function of U, we obtain:

Prob = exp(U)/(1+exp(U))

Where U is some mathematical combination of explanatory economic properties such as income, price, operating cost, etc. that represents the consumer utility of the appliance. The above equation thus defines the logit probability of purchase model. There is generally a constant term in the definition of the utility function that is often set by data that provides the probability in a reference year. The value of the utility in the reference year can be determined by inverting the above equation:

$U_0 = \ln(Prob_0/(1-Prob_0))$

Where U_0 is the consumer utility in the reference year and where $Prob_0$ is the probability in the reference year.

Except for new housing purchases and non-owner to owner conversions, the probability functions depend not only on economic parameters, but the age of the appliance that is being replaced. While other (non-economic) characteristics may play a role in consumer decisions, we obtain a good fit to historical shipments using our model without those characteristics.

Replacement Probability. Data often exist for age-dependent replacement probabilities for appliances. At the least there are data on the age at which appliances tend to be retired with some range of retirement ages. This generally provides an annual retirement probability that is essentially zero for several years and then ramps up from zero to 1 at the maximum age of the appliance when it is certain that it will be retired.

Early Replacement. The sources of data that are typically available for calibrating early replacement probabilities are surveys of consumers that ask them the reason for purchasing or replacing the appliance. In such surveys some consumers will say that they are replacing the old appliance for remodeling or simply to have a new more up-to-date model.

Similar to repair probabilities, we assume that early replacement probabilities are zero for new appliances and increase with the age of the appliance. We pick a linearly increasing probability function where the amplitude of this function is calibrated by calibrating the fraction of early replacements in a reference year with data.

We consider early replacements to be a consumer decision that will be fairly sensitive to economic influences such as price, operating costs, and income. We therefore assign a different logit probability function for each age category that has the same coefficients, but whose constant term is calibrated by the value of the probability for that age category in the reference year.

New Housing & Changes of Residence. For appliance purchases induced by new housing purchases and changes of residences, a simple binary logit market share equation is sufficient to model consumer purchase behavior. We assume that the new housing market is represented by new housing completions and that the market of move-related purchases, major remodels and add-ons are represented by a market that is proportional to new housing completions.

Appliance Removals. We calculate the removals of old appliances due to remodeling, and the removal of houses from the housing stock. The removal of old housing stock is calculated by subtracting the net increase in housing stock from the number of housing completions. The difference is the number of housing units removed from stock. Meanwhile remodels and changes of residence (moves) are assumed to be proportional housing completions. Appliances are assumed to be removed from stock at a rate that is equal to the stock saturation of the appliance times the remodels and moves plus the housing stock removals.

Applications

In this paper we present some simplified applications to illustrate the explanatory power and mathematical properties of our modeling approach. Models currently in use in the standards-setting process are more complicated and detailed than those presented here. For detailed forecast results for particular appliances, see the the U.S. Department of Energy, Energy Efficiency and Renewable Energy website (http://www.eren.doe.gov/).

Below, we illustrate simplified model applications for both clothes washers and central air conditioners. Clothes washers represent a relatively saturated market where consumers have had the financial capacity to afford clothes washers for decades. Another particular feature of the clothes washer market is that it had a fairly complicated competitive dynamics with wringer washers before 1970. Central air conditioners appear to have lower consumer utility than clothes washers because the market for central air conditioners and heat pumps is just now becoming mature and saturated. The greater disutility of central air conditioners stems mostly from their much higher price and the existence of fans and room air conditioners as alternatives. In addition, central air conditioners within the past few decades had prices that represented over 10% of annual household income. The high price combined with competition from room air conditioners and fans means that decreases ~~in~~ price and increases in income have had a greater impact on the purchase of central air conditioning equipment.

We consider the contribution from:

1. New housing and change of residence
2. Early replacement
3. Replacement (break down).

We describe the new housing and existing housing market as a market that is proportional to housing completions. We model the early replacement decisions with a probability function increasing linearly with appliance age. Meanwhile we model the appliance breakdown probability function as a probability function that is 0.5 at a particular age, and which is linearly increasing within a particular age range of about ten years.

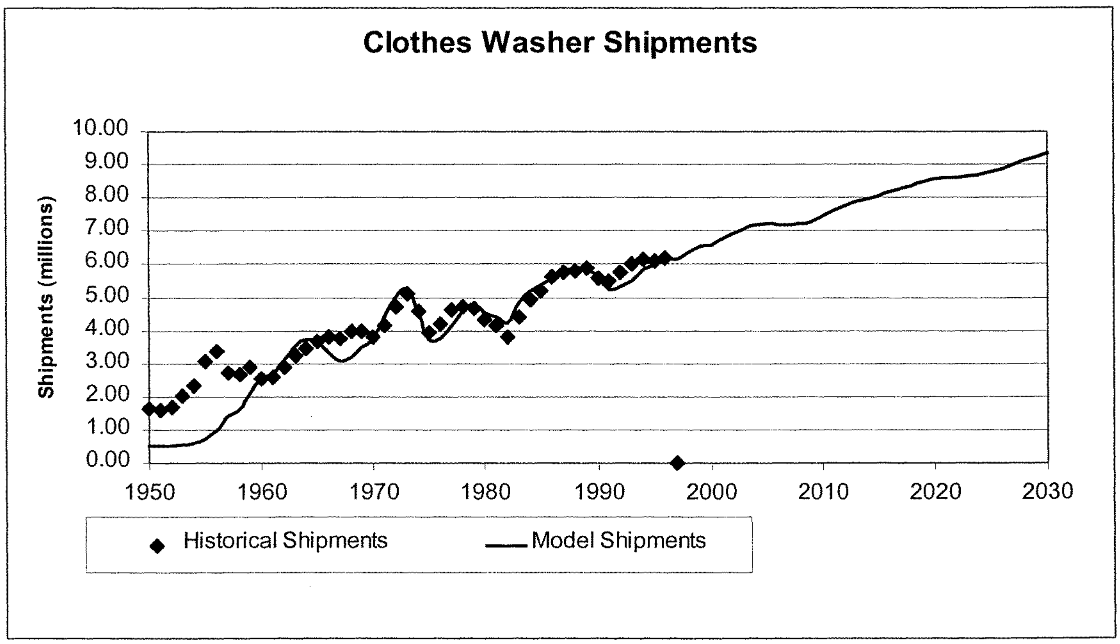

Figure 4. Comparison of model forecast and historical clothes washer shipments.

Results

We implement the models in a simple spreadsheet for both clothes washers and central air conditioning equipment. We then examine how well these fairly simple accounting models can describe the historical shipments of these appliances.

Clothes Washers

Figure 4 shows the results of dis-aggregated shipments model for clothes washers. There are four parameters in the model: (1) The relative size of the remodel/moves market, (2) The amplitude of the early replacement probability, (3) The new housing and remodel market share in 1996, (4) The price coefficient.

Of these parameters, two can be fixed by data. We constrain the amplitude of the early replacement function to be such that 27% of sales in 1996 are early replacements consistent with Association of Household Appliance Manufacturer (AHAM) data [AHAM, 1997]. We also set the market share of clothes washers in new housing in 1996 to its approximate measured value of 82%. In addition, for our price model we assume a continuing real price deflation of 2% per year.

We then adjust the two remaining parameters to fit the historical data. The result is a fit that matches the historical data between 1970 and 1996 with 5.5% RMS error as illustrated in figure 4. The implicit measurement of the price coefficient is –0.0024, which gives a utility function of ($U = U_{1996} - 0.0024 * (Price - Price_{1996})$). To translate this coefficient into an elasticity value, we need to compare sales forecasts for difference price scenarios because there are fairly complicated accounting constraints between different sub-markets of the clothes washer sales. In this particular case, the estimated long-term purchase price elasticity is approximately –0.1 at 2005.

Also note that the model does not predict shipments very well for the period of 1950 to 1970. This is because during this period, people are replacing wringer washers with automatic washers, and we have no information on the stock, age distribution, and replacement function of the wringer washers that are being exchanged for automatic washers. But since this exchange is complete by 1970, wringer washers no longer play a role in the market, therefore it has little or no effect on forecasts after that date.

Air Conditioning Equipment

Figure 5 shows the results of a dis-aggregated shipment model for air conditioning equipment. There are four parameters in the model: (1) The relative size of the remodel market, (2) The amplitude of the early replacement probability, (3) The new housing and remodel market share in 1996, and (4) The price coefficient.

Of these parameters, two can be fixed by data. We constrain the amplitude of the early replacement function to be such that 29% of sales in 1987 are early replacements consistent with ARI data. We also set the market share of central air conditioning in new housing in 1996 to its approximate measured value of 75% (slightly less than published saturations for new single family homes).

We then adjust the two remaining parameters to fit the historical data. The result is a fit that matches the historical data between 1970 and 1996 with 8.5% RMS error as illustrated in figure 5. The implicit measurement of the price coefficient is –0.001. Performing an explicit purchase price elasticity calculation at 2005 we obtain an over-all market elasticity of approximately –0.3.

Like for clothes washers, the over-all long-term market elasticity for air conditioning equipment appears to be substantially greater than –1. This implies that incremental across-the-board price increases will result in over-all revenue increases for the industry. This means that standards that enforce higher product quality and consequent higher product costs can contribute to enhancing revenues in the industry.

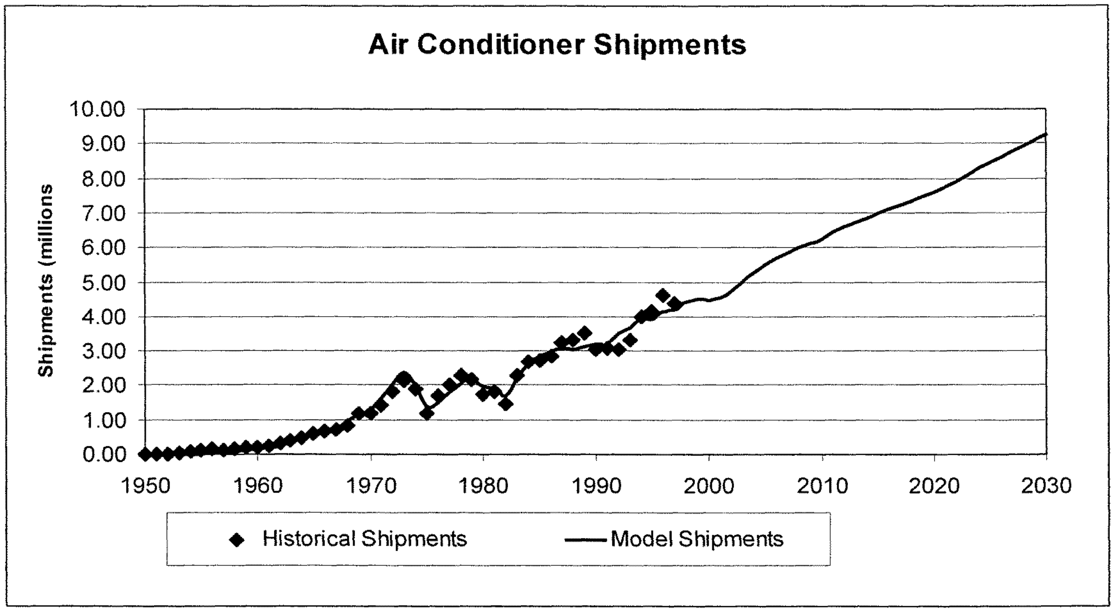

Figure 5: Comparison of model and historical unitary air conditioning product shipments.

Conclusions

Dis-aggregated economic accounting models with probabilistic descriptions of consumer decisions can provide constrained forecasts of appliance shipments. These forecasting methods can provide mathematical descriptions of appliance shipments dynamics that deviate from historical shipments data by only 5% to 10%. This allows us to provide constrained estimates of long-term consumer price elasticity, and forecasts of shifts in appliance markets. Such forecasts are an important part of estimating impacts of energy efficiency standards.

For both clothes washers and air conditioning equipment, the over-all long-term market elasticity the appliances appears to be substantially greater than –1. This implies that incremental across-the-board price increases will result in over-all revenue increases for the respective industries. This means that standards that enforce higher product quality and consequent higher product costs can contribute to enhancing the gross revenues of the industry. Note that higher revenues do not necessarily translate into higher industry profits and greater industry value, but they provide some potential for greater profits. Whether this potential is realized depends on the degree to which manufacturer markups can be maintained, and costs can be passed through to the consumer given the particular competitive environment of the industry.

The enhanced forecasting models and capability that we present in this paper contributes to the standard-setting process. The ability to accurately forecast appliance sales and shipments decreases risk and uncertainty in the formulation and implementation of efficiency standards. Through increased information and predictive ability the ability to design regulatory scenarios for improving the quality, the economic benefits, and the energy efficiency of residential appliances can be enhanced with greater certainty.

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